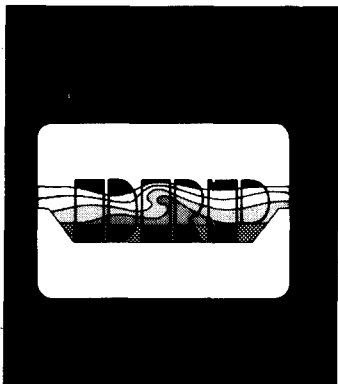
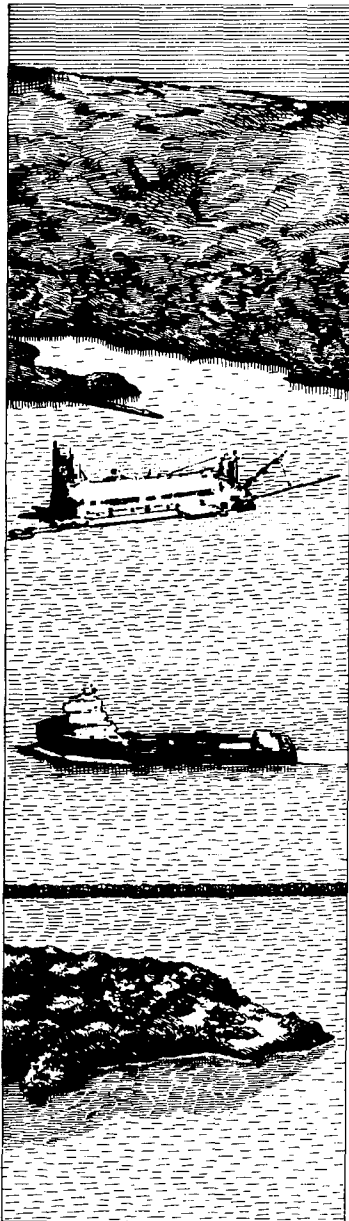




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DREDGING RESEARCH PROGRAM

CONTRACT REPORT DRP-93-3

GEOTECHNICAL FACTORS IN THE DREDGEABILITY OF SEDIMENTS

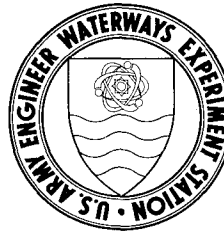
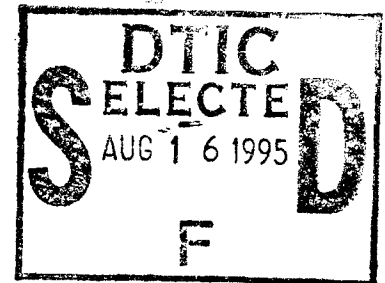
Report 4

REDUCING THE IMPACT OF CONTRACT CLAIMS

by

S. Joseph Spigolon

SJS Corporation
Coos Bay, Oregon 97420



May 1995

Report 4 of a Series

Approved for Public Release; Distribution Unlimited

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Under Work Unit 32471

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The Dredging Research Program (DRP) is a seven-year program of the U.S. Army Corps of Engineers. DRP research is managed in these five technical areas:

- Area 1 - Analysis of Dredged Material Placed in Open Water
- Area 2 - Material Properties Related to Navigation and Dredging
- Area 3 - Dredge Plant Equipment and Systems Processes
- Area 4 - Vessel Positioning, Survey Controls, and Dredge Monitoring Systems
- Area 5 - Management of Dredging Projects

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US Army Corps
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Dredging Research Program Report Summary



Geotechnical Factors in the Dredgeability of Sediments; Report 4, Reducing the Impact of Contract Claims (CR DRP-93-3)

ISSUE: The major purpose of the Dredging Research Program (DRP) was to reduce the cost of dredging to a minimum consistent with mission performance and environmental responsibility. One means of accomplishing this mandate is to reduce the impact of contract claims associated with dredging projects.

RESEARCH: Observations gathered in pursuit of information contained in the report were derived from four sources:

- Published literature related to construction claims (particularly dredging contracts).
- Telephone interviews with dredging contractors, dredging consultants, and Corps of Engineers geotechnical and dredging operations personnel.
- Review of several recent differing-site-condition claims involving large sums of money.
- DRP technical reports (published and in draft), technical notes, and information exchange bulletins.

SUMMARY: Geotechnical engineering and other DRP contributions can be applied to the understanding and reduction of those factors that lead to differing-site-condition claims. Recommendations based on the information produced research for the study include improved communications between the Corps of Engineers and prospective dredging contractors as well as improved personnel proficiency for both contractors and the Corps of Engineers.

AVAILABILITY OF REPORT: The report is available through the Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, telephone number (601) 634-2355. National Technical Information Service (NTIS) numbers may be requested from WES Librarians. To purchase a copy of the report, call NTIS at (703) 487-4780.

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Geotechnical Factors in the Dredgeability of Sediments

Report 4 Reducing the Impact of Contract Claims

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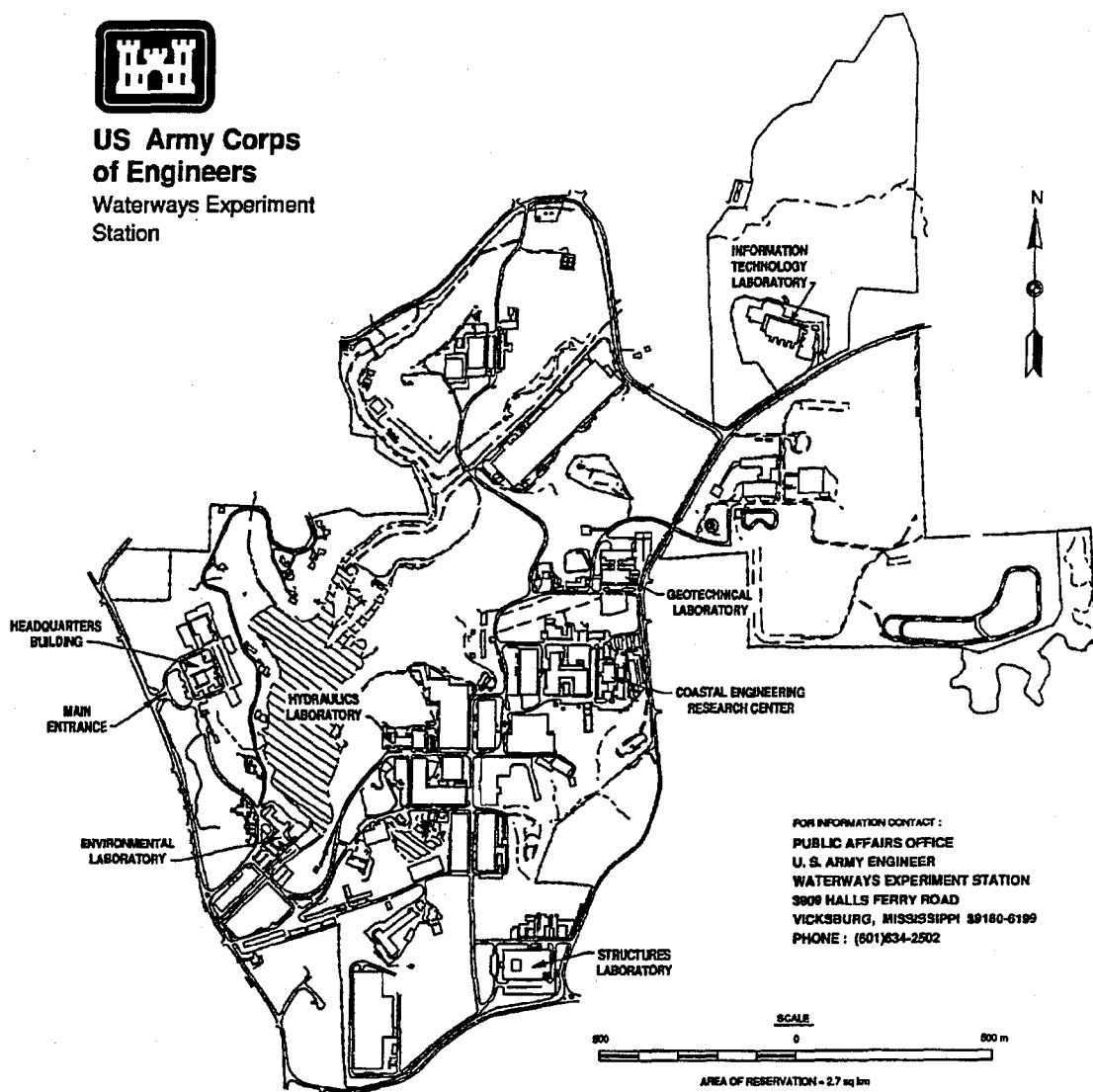
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Preface

This report was prepared under Contract No. DACW39-93-M-5392, dated 16 June 1993, for the U.S. Army Engineer Waterways Experiment Station (WES) under Dredging Research Program (DRP) Technical Area 2, Work Unit No. 32471, "Descriptors for Bottom Sediments to be Dredged." The DRP is sponsored by Headquarters, U.S. Army Corps of Engineers. Technical Monitor for Technical Area 2 was Mr. Barry W. Holliday; Chief Technical Monitor was Mr. Robert H. Campbell.

This report was written by Dr. S. Joseph Spigolon, Engineering Consultant, SJS Corporation, Coos Bay, Oregon, under the technical monitoring of Dr. Jack Fowler, Principal Investigator, Soil Mechanics Branch (SMB), Soil and Rock Mechanics Division (S&RMD), Geotechnical Laboratory (GL), WES, Mr. W. Milton Myers, Chief, SMB, GL; Dr. Don C. Banks, Chief, S&RMD, GL; and Dr. W. F. Marcuson III, Chief, GL. Dr. Banks was also the Manager for Technical Area 2, "Material Properties Related to Navigation and Dredging," of the DRP. Mr. E. Clark McNair, Jr., and Dr. Lyndell Z. Hales were Manager and Assistant Manager, respectively, of the DRP, Coastal Engineering Research Center (CERC), WES. Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., were Director and Assistant Director, respectively, of CERC, which oversees the DRP.

During the publication of this report, Commander of WES was COL Bruce K. Howard, EN. Dr. Robert W. Whalin was Director.

Additional information on this report can be obtained from Mr. E. Clark McNair, Jr., DRP Program Manager, at (601) 634-2070.

1 Introduction

The Dredging Research Program (DRP) at the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, was a 7-year program started in 1987. The purpose of the DRP was stated in the Dredging Research Program Development Report (Calhoun et al. 1986):

The DRP will have one major purpose: reduce the cost of dredging to a minimum consistent with mission performance and environmental responsibility. This can be accomplished in a variety of ways, including:

- a. Increasing the efficiency of a process, operation, or piece of equipment.
- b. Reducing the impact of contract claims.
- c. Defining operational requirements more comprehensively and accurately.
- d. Sharing Field Operating Agency successes in reducing costs and modifying or expanding them for Corps-wide application.

Objective

The objective of this report is to present a summary discussion of the contributions of the geotechnical engineering and other knowledge gained in the DRP as they apply to item *b* above, i.e., *reducing the impact of contract claims in dredging projects*.

Several of the research studies conducted in the DRP have resulted in knowledge or insight that has the potential to reduce the impact of factors that lead to contract claims. Most of the information and research knowledge that is applicable to reducing the impact of contract claims was developed in DRP Technical Area 2, *Material Properties Related to Navigation and Dredging*, and DRP Technical Area 4, *Vessel Positioning, Survey Controls, and Dredge Monitoring*.

Scope of the Report

Dredging project contract claims can arise as a result of various factors that cause the contractor to experience additional costs and/or a time delay that result in lost profits and that are not under the contractor's control. This includes such factors as differing site conditions, adverse weather, unusually rough sea conditions, change orders, and other unexpected time delays. This report will be limited to a study of the DRP's contribution to minimizing the impact of *differing site conditions* claims.

The observations presented in this report were derived from four major sources. A review was made of the limited amount of published literature dealing with construction, and particularly dredging, claims. Telephone interviews were conducted with dredging contractors, dredging consultants, and Corps of Engineers geotechnical and dredging operations personnel. Several recent contract claims concerning differing site conditions and involving large sums of money were reviewed. All pertinent DRP documents published by WES were studied, including DRP technical reports, technical notes, and information exchange bulletins.

Organization of Remainder of Report

Chapter 2 presents a list of the major factors that contribute to differing site conditions claims. The sources of the listing are described. Each factor is discussed in detail.

Chapter 3 contains a discussion of the DRP's contributions to the improvement of strategies or enhancing subsurface investigations in soil and rock that may prevent some future differing site conditions claims in dredging projects. Requirements for a sufficient geotechnical investigation are explored. Equipment and methods developed for more cost-effective subsurface investigations are discussed.

Chapter 4 examines other contributions of the DRP to reducing the impact of differing site conditions claims. These include studies that may lead to (a) improving the completeness, clarity, and terminology of contract documents and other presentations of site conditions; (b) improving understanding by contractor and Corps personnel of relationships between sediment characteristics and dredgeability; and (c) improving Corps capability to evaluate job-related performance or the contractor's work.

Chapter 5 contains a summary of this report and recommendations for improving the effort to reduce the impact of differing site conditions claims in dredging projects.

2 Factors Involved in Claims of Differing Site Conditions

There are risks inherent in any type of construction, including dredging. The risks to the owner of a dredging project are due to site conditions, known or unknown, surface and subsurface, that may adversely affect the legitimate cost of having the specified work done by a contractor. The risks to the contractor include all the unforeseen surface and subsurface conditions that may adversely affect the contractor's production rate, costs, and legitimate profit. Risks to the dredging contractor include such factors as unexpected changes in site conditions, including the character and location of the sediment to be dredged, weather, traffic delays, fuel and labor costs, labor disputes, unexpected shoaling, etc. Each party to a proposed dredging project has decisions to make, and commensurate risks to bear.

The owner decides where and when dredging work is to be done. The owner also establishes the specifications for the conduct of the work. The dredging contractor has no control over the owner's decision process. The owner is also responsible to the contractor for (a) disclosing to the dredging contractor all of the owner's information about subsurface conditions and other site conditions that may reasonably be expected to have potentially adverse effects upon the contractor's performance, (b) prompt evaluation of the acceptability of work done, and (c) on-time payment to the contractor for acceptable work.

The contractor has control over his own operations, including (a) acquiring the knowledge, experience, and capability to understand and execute all of the requirements of the contract and specifications, (b) providing all financing of his own organization before, during, and after construction, (c) providing equipment adequate for the project through purchase (or lease), maintenance, availability, and mobilization, (d) providing construction materials when and where required, (e) providing competent operating personnel as needed, (f) providing capable supervision of the project, and (g) scheduling of operations to meet contract time provisions.

FAR Changed-Conditions Clause

The federal government, the major purchaser of dredging in the United States, has recognized that it, as the owner, has the responsibility to pay the dredging contractor's legitimate claims for the adverse effects of an unexpected change in site conditions. In all Corps of Engineers contracts for dredging, the Federal Acquisition Regulations (FAR) Differing Site Conditions/Changed Conditions clause, 48 C.F.R. 52.236-2, reads as follows:

"(a) The Contractor shall promptly, and before the conditions are disturbed, give a written notice to the Contracting Officer of (1) subsurface or latent physical conditions at the site which differ materially from those indicated in this contract, or (2) unknown physical conditions at the site, of an unusual nature, which differ materially from those ordinarily encountered and generally recognized as inhering in work of the character provided for in the contract.

(b) The Contracting Officer shall investigate the site conditions promptly after receiving the notice. If the conditions do materially so differ and cause an increase or decrease in the Contractor's cost of, or the time required for, performing any part of the work under this contract, whether or not changed as a result of the conditions, an equitable adjustment shall be made under this clause and the contract modified in writing accordingly.

(c) No request by the Contractor for an equitable adjustment to the contract under this clause shall be allowed, unless the Contractor has given the written notice required: *provided*, that the time prescribed in (a) above for giving written notice may be extended by the Contracting Officer.

(d) No request by the Contractor for an equitable adjustment to the contract for differing site conditions shall be allowed if made after final payment under this contract."

There is a distinction between the two types of differing site conditions allowed in the FAR differing site conditions contract clause (Rubin et al. 1983, 1992):

- a. Type I refers to misrepresentation of site conditions, intentional or innocent.
- b. Type II deals with conditions that could not have been reasonably foreseen by either the contractor or the owner.

Sources of Research Information

A study was made of the major causes of differing site conditions claims. The sources of information used in the development of this study report were:

- a. *Summaries.* A search for summaries of recent court cases and alternative dispute resolution (ADR) proceedings involving dredging claims.
- b. *Case histories.* A review of some recent project histories in which major dredging claims were filed.
- c. *Interviews.* Telephone interviews with a number of dredging contractors, dredging consultants, and Corps of Engineers personnel.

Recent court and ADR cases

A study was made of dredging claims and related disputes by personnel of the WES Hydraulics Laboratory. The results are contained in a Memorandum for Record (Scott 1992) to the Hydraulics Laboratory. Two information sources were used. The legal staff at WES made a computer search of the WESTLAW and CMIS databases. That search yielded 57 court cases for review, dating from 1954 to 1990. The legal staff also requested, from all U.S. Army Corps of Engineers (USACE) Divisions and Districts, information on dredging disputes decided under ADR proceedings. The Mobile District responded with 14 claims filed between 1985 and 1992, the New Orleans District replied with 19 claims from the period 1980 to 1991, and the Vicksburg District, Little Rock District, and North Central Division responded with one claim each.

The 57 cases decided by the U.S. Claims Court, Engineering Board of Contract Appeals, U.S. District Courts, and the U.S. Supreme Court were categorized as follows:

- a. Fifteen cases involving changed conditions. Of these,
 - (1) Six cases were for unanticipated shoaling due to extreme weather conditions.
 - (2) Five cases were for unexpected shoaling from bank erosion or scour.
 - (3) Four cases were for unanticipated rough seas or unexpected changes in river levels.
- b. Twenty cases involved differing site conditions. Of these,

- (1) Thirteen claims involved rock, boulders, cobbles, and/or gravel not indicated in the project specifications.
 - (2) Four claims were for materials that were not adequately described and found unsuitable for use in levees or dikes.
 - (3) Two claims were for encountering virgin (previously not dredged) materials in a maintenance project.
 - (4) One claim involved the encountering of unspecified hazardous materials.
- c. Seven cases involved differences in the Corps of Engineers' estimate of quantities to be dredged. This included differences in the quantities estimated to be used to build dikes, inaccurate estimates of rock quantities, and in specifications about methods for payment for overdepth dredging.
- d. Fifteen cases were for "miscellaneous" disputes.

Of the four Districts and one Division responding to the request for ADR case histories, the responses were as follows:

- a. Fourteen cases were from the Mobile District. Of these,
- (1) Seven claims were for differences in estimated quantities.
 - (2) Five claims were for differing site conditions.
 - (3) Two claims were for "miscellaneous" situations.
- b. Nineteen cases were from the New Orleans District. Of these,
- (1) Three claims were for differences in estimated quantities.
 - (2) Eleven claims were for differing site conditions.
 - (3) Five claims were for "miscellaneous" situations.
- c. The remaining three cases, reported by the Little Rock and Vicksburg Districts and the North Central Division, were all for differing site conditions.

Scott's (1992) Memorandum for Record does not indicate the causes for the "differences in estimated quantities" claims. They could have resulted from either (a) inadequate knowledge of the actual character and stratification of the sediments or (b) errors in calculation procedures. It is most probable that the errors, if they occurred at all, were the result of insufficient subsurface investigations.

It appears from the reviewed court cases that the combination of "differing site conditions" and "differences in estimated quantities," resulting from inadequate subsurface investigation programs, accounted for 47 percent of the claims reaching the courts. Of the claims reported by the Districts and the one Division as being resolved by ADR, the combination of "differing site conditions" and "differences in estimated quantities" accounted for 81 percent of all claims.

Case histories of recent claims

The files of four recent claims involving substantial sums of money were reviewed. One or more of these cases is still (1994) in contention. Therefore, none of the comments made here should be construed as a conclusion or an endorsement. The four case files studied were: (1) the Baltimore Harbor claim, (2) the York Spit II claims, by two of the contractors involved, (3) the Anchorage, Alaska, claim, and (4) the Tennessee-Tombigbee Waterway claim, discussed by Turner (1986) and Casey (1987).

The four cases had several similarities. All involved soil as the sediment to be dredged. In each case, the contractor claimed that the subsurface investigation reported in the contract documents did not clearly disclose the actual subsurface conditions. In some cases, equipment was mobilized to dredge the sediments described in the contract documents and later was found to be not as adapted to the site as expected.

Telephone Interviews

During telephone interviews conducted in early March, 1994, several organizations on the Pacific, Gulf, and Atlantic coasts were asked two questions: (1) What, in your experience, have been the main contributing factors to differing site conditions claims? and (2) Do you have any suggestions for reducing the impact of dredging claims? The persons interviewed were, in alphabetical order:

- a. Renato Basurto, USAE District, New Orleans
- b. Al Fletcher, USAE District, Jacksonville
- c. Gerald Greener, Office, Chief of Engineers, Washington, DC
- d. Greg Hartman, Hartman & Associates, Seattle, WA
- e. Brion Lindholm, Weeks Marine, Inc., Cranford, NJ
- f. William H. Muesser, Jr., Pacific Division Office, Great Lakes Dredge & Dock Co., Oakland, CA
- g. Robert Parry, USAE District, Seattle

- h.* Hardy J. Smith, USAE Waterways Experiment Station, Vicksburg, MS
- i.* Ancil Taylor, Bean Dredging Corp., Belle Chasse, LA
- j.* Thomas M. Turner, Turner Consultants, Inc., Sarasota, FL
- k.* Thomas Verna, Office, Chief of Engineers, Washington, DC

All comments made by the persons interviewed were recorded and analyzed. As indicated to the persons interviewed, no direct quotations or link of their names with any of their comments are included in this report. However, their collective comments were included in the analysis that led to the summary given below.

All of the persons interviewed stated that insufficient subsurface investigations were a major factor in differing site conditions claims. There was agreement among several of the interviewed persons about each of the other factors, all of which are reflected in the listing shown below.

Factors Leading to Claims of Differing Site Conditions

Based on the studies made for this report, described above, it appears that differing site conditions claims on dredging projects result from one or a combination of two factors, when they are present on a project:

1. Lack of sufficient and effective communication between the owner (the Corps of Engineers) and dredging contractors, prospective or actual. This includes:
 - a.* Insufficient geotechnical subsurface investigations.
 - b.* Insufficient and/or unclear descriptions of site conditions in contract documents. Also, there may be a lack of consistent terminology.
2. Lack of adequate proficiency in the personnel, equipment, and/or procedures of dredging contractors and/or the Corps of Engineers. This includes both:
 - a.* Lack of adequate contractor proficiency, including:
 - (1) Lack of full understanding of the project surface and subsurface conditions and how they might affect the dredging project plan and operations.

- (2) Inadequacy of equipment and/or personnel for the specific project.
- (3) Inadequacy of the contractor's organization to finance, plan, supervise, and operate the project.
- (4) Incomplete or misinterpreted operating records; assumption of wrong cause of delay or interruption of dredging.

b. Lack of adequate Corps of Engineers proficiency, including:

- (1) Lack of understanding and experience regarding the contractor's information needs before and during dredging operations.
- (2) Imprecise and unclear project specifications.
- (3) Imprecise, inadequately defined, and/or poorly executed Quality Assurance/Quality Verification (QA/QV) evaluation and acceptance procedures.
- (4) Estimating programs that do not reflect the reality of dredge operating conditions.

Waggoner (1981) presented a "top ten" list of contributing factors to *construction* claims for differing site conditions that contains essentially the same factors as the one given above. Waggoner distinguishes between *justifiable* and *unjustified* claims. Justifiable claims are based on the factors listed above. All of the factors in his list, and in the one given above, assume that both the contractor and the owner are completely honest and sincere, i.e., there is no conscious attempt at fraud or misrepresentation of facts. Unjustified claims, on the other hand, are not so much a question of obtaining equity in a specific situation, but of solving some business problems. Business problems leading to unjustified claims include such matters as (a) planned low bidding, expecting to recoup through claims, (b) being inexperienced and/or unqualified, and in trouble with the project, hoping to salvage the job through a claim, (c) retaliation for what the contractor perceives as unfair treatment or over-rigid inspection.

Insufficient geotechnical site Investigations

The major contributor to claims is the lack of sufficient subsurface information. Development of a dredging plan, and a cost estimate, requires that both the contractor and the government estimator be able to make a reasonable judgment about the location, horizontal and vertical, and the dredgeability characteristics of all sediment deposits in the dredging prism. Mobilization and employment of unsuitable or inefficient equipment, not matched to the characteristics of the specific sediment, can be very costly. There is sometimes confusion between the needs of maintenance as opposed to new work. In maintenance work, there usually are

acceptable historical records of productivity. In new work, the owner and the contractor are substituting the subsurface investigation for the history.

There appear to be two schools of thought about the desired magnitude of subsurface investigations by the owner prior to letting a dredging contract. One attitude is that the owner should investigate only just so far as needed for design purposes. This probably stems from the time when most Corps of Engineers dredging was done by force account, i.e., by its own forces. This school feels that only a minimum of information should be created and given to the contractor because the information may otherwise be misinterpreted and result in a claim. Even though limited in time, prospective contractors should have the right to make their own explorations and evaluations.

The other school feels that the owner has much more time for subsurface investigation than the prospective contractors. By providing all contractors with the same extensive and useful subsurface information, there is a "level playing field" and the contractor assumes less risk. All contractors are then making bid estimates based on the same information and the owner assumes all of the risks due to unknown subsurface conditions. This is expected to inhibit the preparation of unreasonably low bids by inexperienced or uninformed contractors, who will later submit costly claims that could have been avoided. This school believes that, over the long term, reducing contractor risk results in the lowest cost.

Insufficient descriptions of site conditions

It is obvious that total, effective communication between the owner and prospective and actual contractors is essential for all concerned. Misunderstandings are a breeding ground for claims, whether based on fact or not. A major source of misunderstandings is insufficient and/or unclear descriptions of site conditions in contract documents, sometimes the result of a lack of consistent terminology. It is unfortunate that, oftentimes, geotechnical engineers and dredging estimators for the contractors and the government do not speak each others' language.

Geotechnical engineers invariably plan and execute subsurface investigations used for dredging contracts, especially the ones used for new work projects. New work projects are not a daily, or even a yearly, event. It is perhaps understandable, then, that geotechnical engineers may not fully comprehend the need to define terms and describe sediments in a manner that contractors and government estimators can understand. One glaring example of this results from the fact that soils are described exclusively in terms of the Unified Soil Classification System (USCS). Knowledge of the median, or 50 percent, grain size is essential for sizing the pump and pipeline needed for the hydraulic transport of soils, particularly sands. The USCS classification groups for sand are far too broad with respect to the median size of grains to define this characteristic in a usable manner. In some parts of the United States, the soils to be dredged have a grain

size distribution with about 50 percent passing the No. 200 screen (0.075 mm), the borderline between fine sand and low plasticity silt. Samples being laboratory tested will randomly fall into either the coarse-grained or the fine-grained categories because of as little as a 1-percent change in the percentage of the sample passing the No. 200 screen. As another factor, knowledge of the in situ strength of the soil or rock is necessary for evaluating its excavatability. Strength determination is not an essential part of the USCS.

Insufficient contractor proficiency

Not all dredging contractors have the personal knowledge or staff capability to fully understand the project's surface and subsurface conditions, as described in contract documents and other reference sources, and how they might affect the dredging project costs, plan, and operations. This often stems from the terminology used by the document preparers and its unfamiliarity to the contractor, particularly when the description is about unusual material behavior or conditions not previously encountered.

Each contractor, large and small, has only a limited amount of dredging plant and personnel available for a specific project. The uncertainties of the bidding process and scheduling of dredging projects and, sometimes, the lack of contractor knowledge and experience, may lead to inadequate equipment and/or poorly trained personnel being supplied to a project. When the equipment and/or personnel cannot function properly, some contractors will file a claim, trying to recoup losses.

Another factor sometimes encountered, particularly with new, underfinanced dredging contractors, is inability of the contractor's organization to finance, plan, supervise, and operate the project in a profitable manner. This is apparently a fact of life with all new businesses and sometimes occurs with older, more established, and overextended companies. Difficulties with the profitable conduct of a dredging project can, and often do, lead to one or more claims, filed with the hope of recouping losses.

Contractors may also file claims due to the incorrect assumption or belief that certain causes of delays or interruptions of dredging are occurring when in fact the delays are really due to some other cause. This often occurs because of incomplete or misinterpreted operating records. In such cases, the contractor may interpret the cause of a costly delay as due to differing site conditions rather than being due to his own operational decisions. The lack of complete operating records has, on occasion, led to the government's rejection of differing site conditions claims.

Insufficient Corps of Engineers proficiency

The Corps of Engineers is a large and varied organization whose personnel are constantly being moved and/or promoted. New work dredging projects are not an everyday occurrence. This means that some Corps personnel working on dredging projects may lack experience and full understanding of the contractor's information needs before and during dredging operations, particularly in new work projects.

Preparers of dredging project specifications are often reluctant to specify the manner in which certain operations can be done by the contractor, even when the known project conditions indicate that only certain types of equipment and/or methods can be successfully used. This results from the current policy of writing performance specifications rather than methods specifications. If a method is specified, and the contractor uses the method and it does not work as expected, then the owner is expected to assume the risk and a claim is inevitably and justifiably filed. If the desired end result only is specified, then the contractor is expected to assume the risks involved. This process allows the contractor to be innovative. This places the burden of preparing end results specifications in a clear and well-understood manner directly on the Corps of Engineers or other owner.

Another cause of disputes, sometimes leading to claims, is the imprecise, inadequately defined, and/or poorly executed QA/QV evaluation and acceptance procedures. Evaluation criteria are typically not well specified, and the inspectors often do not understand them. QA/QV evaluation procedures must be defined clearly so that both inspectors and contractors know what to expect. If, for example, one criterion is sediment density, then how is it to be measured? And, where is it to be measured? Another evaluation factor deals with production rates. But, the production rate of what? Does it involve a specific dredge with specific material and specific pipeline? Is it production measured by before and after surveys? Is it based on pump horsepower or fuel consumption only?

The Corps of Engineers' current estimating programs are based on Engineer Regulation (ER) 1110-2-1300 (Headquarters, USACE 1985). The present methodology used in the ER is due to the pioneering efforts of Adolph Mohr. Mr. Mohr has clearly stated (Mohr 1980):

The table and graphs shown in this paper [and in ER 1110-2-1300] are provided to avoid complicated mathematical considerations and were developed by the writer. They are essentially empirical, that is, based on actual observed performance of government owned and private plant. . . . *There exists no complete or rigorous backup for the data presented* [Italics added].

The effect of the material to be dredged on production is very pronounced, yet its precise evaluation is difficult. . . . The hourly production rates in the standard table are prepared for free-flowing sand

having an in-place density of about 2,000 g/L. These rates can be adjusted by a factor which considers the variations in the average in-place densities of different relatively free-flowing, noncohesive materials such as mud, silt, sand, or a mixture thereof. The rationale used in this consideration is based on the observation that in these materials the effluent density is nearly independent of the in-place density.

Several potential difficulties appear in the methodology contained in the Mohr paper and the resulting ER 1110-2-1300. These include:

- a. Material factors are based on vague definitions of material type, including the "Average in-place density." For the type of material for which the ER is supposed to be used, the determination of in-place density is virtually impossible (Spigolon 1993b) by any direct sampling method. There is, in fact, no recognized geotechnical definition for "mud."
- b. Material factors make no differentiation in the effect on production rate of differences in excavation effort for loose versus dense, coarse-grained materials or for soft versus hard, fine-grained materials. There is no way to account for the differences in pumping efforts for materials of differing median grain size.
- c. As stated by Mohr (1980), the chart of factors for different in-place densities is only for free-flowing materials "and must not be used for cohesive clays, heavy gravel, cobbles, broken stone, or any cemented materials."

Most of these potential difficulties have been recognized by the Corps of Engineers groups responsible for the Corps' estimating programs. Accordingly, the efforts started by Adolph Mohr have been reviewed and expanded. In recognition of some of the limitations listed above, a new Corps of Engineers estimating program has been developed and is due for field review in 1994. In the new program, it is anticipated that "material factors" can be derived from any of several sources, including ER 1110-2-1300, any of the several privately developed dredging evaluation programs, or historical records. Mohr recognized the need for such continual reappraisal of the material factors when he stated (Mohr 1980): "Any comments to improve this data or the approach to it would be greatly appreciated."

3 DRP Contributions to Subsurface Investigations

Several investigators have prepared research reports for the DRP dealing with geotechnical subsurface investigations. In a group of reports, Mr. R. F. Ballard and his associates at the WES Geotechnical Laboratory developed and presented a system for geophysical acoustic impedance surveys of the subsurface sediments (Harmon and Ballard 1991; Ballard et al. 1993; McGee, Ballard, and Caulfield, in preparation). The equipment is boat-borne and provides a rapid, relatively inexpensive overview of the location and areal distribution, and the density and type, of sediments in the proposed dredging prism.

Mr. H. J. Smith, also of the WES Geotechnical Laboratory, described the use of the drilling parameter recorder (DPR) for obtaining a continuous record of the drill rig's response to rock drilling effort (Smith 1991a). Smith also discussed the use of the point load test as a means of rapidly measuring the strength of rock as an alternative to more expensive and time-consuming compressive strength tests of rock cores (Smith 1991b). Both of these topics were discussed in detail in a summary report (Smith, in preparation).

Messrs. J. B. Smith and J. E. Clausner reported on the development of a very inexpensive, shop-made vibrating tube device for obtaining samples from sands and fine-grained sediments in shallow water (Smith and Clausner 1993). Vibracoring is a rapid and relatively simple way of obtaining continuous, representative, but disturbed samples. Continuous samples may prove to be of great value in, for example, environmental studies of sediments or in studies of recently shoaled maintenance material.

Under the direction of Dr. J. Fowler, Geotechnical Laboratory, WES, two geotechnical engineering contractors prepared studies of subsurface investigations in soil sediments. Dr. S. J. Spigolon investigated the geotechnical descriptors needed for defining soil properties during a subsurface investigation (Spigolon 1993a, in preparation (a)). This was followed by a study report of the factors involved in developing a subsurface investigation strategy, or plan (Spigolon 1993b, in preparation (b)). In

association with Dr. R. M. Bakeer of Tulane University, a knowledge-based expert system computer program (Spigolon and Bakeer 1993, in preparation (b), (e), (f)) was developed to provide guidance to geotechnical engineers and engineering geologists in the selection of suitable field sampling and testing methods.

Subsurface Investigation Strategy Decisions

Subsurface investigations for dredging projects have requirements that are significantly different from those for the typical foundation engineering project. Geotechnical engineering foundation investigations for structures, off- or onshore, generally cover small areas, sometimes to great depths. Existing land-based techniques and equipment are best suited to serve the primary purpose of performing exacting geotechnical field soils tests and obtaining high quality samples for laboratory shear strength tests. Dredging projects, on the other hand, do not require the knowledge of soil strength and texture with the precision needed for foundation engineering. Average values and ranges of values of the pertinent geotechnical properties are generally sufficient.

Dredging site investigations are similar in scope to those made for highways, canals, and pipelines in the sense that they involve long, narrow lengths, or large areas, and shallow depths in the soil to be excavated and removed. Maintenance work usually consists of 1 m (3 ft) or less of shoaled material to be removed. New work channel deepening projects typically involve 1.5 to 3 m (5 to 10 ft) of excavation. New channel projects may involve greater depths of excavation.

A number of decisions must be made in answer to questions that arise in the planning and execution of a geotechnical subbottom investigation for a dredging project, whether for new work or for maintenance dredging. DRP geotechnical engineering answers to the following questions will be presented in the following sections in this order:

- (1) Is a subsurface geotechnical investigation necessary? Will it be useful for saving money on the project?
- (2) If it will be useful, what will be its magnitude? How much money and time should be budgeted?
- (3) Which sediment characteristics must be identified and described?
- (4) What kind of investigation strategy, or plan, is to be used? What are the steps to follow?
- (5) If sampling and testing are to be done, where will the individual borings, pits, or probings be located? How useful are geophysical surveys?

- (6) How will the sediment characteristics be determined? At each exploration site, which equipment and methods should be used to obtain samples and/or make field tests?
- (7) How will the sampling or testing depth be reached? Borings? Test pits? Probings? How will the borings, pits, or probings be made? What kind of work platform is needed?

Question 1: Usefulness of Geotechnical Subsurface Investigation

As discussed in Chapter 2 of this report, a major factor leading to differing site conditions claims is the insufficiency of valid geotechnical subsurface information. It may be argued that the government will pay for any differing site conditions encountered by the contractor and, therefore, does not need to do extensive geotechnical subsurface investigation. However, in both maintenance and new work projects, the lack of sufficient information may cause any one or a combination of three problems:

- (1) The government estimator does not have a true picture of the geotechnical soil profile and, therefore, cannot develop a valid estimate.
- (2) Contractors are not using the same geotechnical soil profile, with the result that the low-bid contractor may unknowingly (or knowingly) be taking higher risks than expected, i.e., there is not a "level playing field," and may attempt to recoup any losses with a claim. The sensible objective, then, should be to provide all contractors with a sufficient amount of geotechnical site information that the only factors that determine who gets the job are their own capabilities to manage personnel, equipment, scheduling, and financing in a profitable manner.
- (3) A contractor, faced with unforeseen costly time delays, may ascribe the cause to differing site conditions rather than due to his own operations. In this case, the lack of knowledge about the presence or absence of differing site conditions can lead to costly and unproductive claims litigation and even wrongful conclusions.

It has been argued (James and Andreae 1978, Spigolon 1993b) that a complete, *sufficient* subsurface investigation for new work projects will save the owner, i.e., the government in most cases, money that would otherwise have been spent on reviewing and defending claims. By disclosing all potential subsurface risk conditions beforehand, although the bids may be slightly higher, the total cost of the project is expected to be much lower.

Most government agencies and contractors have not felt that any subsurface investigation is needed on maintenance projects, especially those where many years of repeated dredging experience is available. There are two situations, revealed by the research for this study, where subsurface investigations would have, or actually have, been useful for maintenance work.

In the first case, the Mississippi River and other rivers have experienced extreme changes in water levels in the past few years, from record lows to massive floods. This means that the amount of shoaling, its specific locations, and the resulting median grain size have not been uniform from year to year. This affects the amount of work to be done and the contractor's pipeline slurry pumping effort.

In the second case, a contractor's change in the size of the excavation equipment from what had been used previously caused an unexpected loss of productivity. Although the project had been dredged several times, there was no *baseline* geotechnical survey to accompany the historical records of smaller equipment usage. Valid geotechnical information may have indicated to the contractor that the larger equipment was not as well-suited to the soils with the specific properties found at that site.

Question 2: Magnitude of a Geotechnical Subsurface Investigation

As discussed in Spigolon (1993b), assuming that a geotechnical subsurface investigation is needed, then the next question regards its magnitude. How much money should be budgeted? This is the question of *sufficiency*. This concept is perhaps best approached from the standpoint of the *value of information*. The magnitude of a subsurface investigation is sufficient when the cost of obtaining an additional increment of geotechnical information becomes greater than the potential savings from possessing the additional information.

Assume, for example, that a dredging contractor is faced with a channel-deepening project. The owner has provided some prior information consisting of geologic literature about the general area and project records containing test boring logs from near the site, but no geotechnical data from within the dredging prism itself. Then the cost associated with this level of geotechnical risk will be (a) the total project cost contained in the bid price plus (b) the cost of reviewing and litigating differing site conditions claims, and (c) the possible cost of paying some or all of the claims. The bid price is affected by (a) the contractor's estimate of costs based on his assumption of what the actual subbottom conditions are, (b) a risk factor to account for those conditions for which he may not be compensated by a valid claim, including his misjudgments about equipment suitability and time to do the work, and (c) very importantly, how eager

the contractor is to get the work and what he thinks he must bid to obtain the contract.

Alternatively, assume that a very extensive geotechnical subsurface investigation has been made and that it is so extensive that the knowledge of the character of the sediment profile can be called *perfect*. Now, how much can the total project cost be reduced? The contractor now has all knowledge beforehand needed to match equipment to sediment type and character, to schedule the correct equipment, and to determine fuel, personnel, and wear costs. This practically eliminates the risk in the project due to lack of knowledge of the characteristics of the materials in the dredging prism. Although the contractor's estimated costs due to perfect knowledge may be higher than before, the reduction of risk should create an overall savings in bid price. This is called the *value of perfect information*, (*VPI*), and represents an upper limit of project savings due to the availability of complete geotechnical information.

Figure 1 graphically demonstrates the monetary value of obtaining a sufficient amount of subsurface information. Every piece of new information derived from an increment of sampling and testing is added to the total information that was previously available. Using the concept of Bayes' Theorem of probability, this results in a relationship similar to a learning curve (which, in effect, it is). The amount that the subsurface investigation information reduces the total project cost, including the bid price and the total cost of claims, is called the *value of sample information* (*VSI*). Each new amount of sample and testing information adds to the total knowledge about the site, but with decreasing value. Starting from a position of very little knowledge, the first amount of sample data increases the contractor's knowledge about the site by a large amount and helps greatly to reduce the risk due to uncertainty about the project sediments. The next amount of valid information increases the contractor's knowledge by a somewhat lesser amount, and so forth. As the amount of information available increases, the *VSI* curve ultimately becomes asymptotic to the *VPI* line.

Assume next that the cost of making a geotechnical subsurface investigation is a linear function of the value of that information in reducing geotechnical risk. This is a somewhat realistic assumption if money and effort are not wasted on meaningless tests for irrelevant soil properties and if the work is efficiently planned and carried out. It is also reasonable to include a fixed cost for mobilization, overhead, and other indirect costs as the intercept of the line. The *cost of obtaining information* (*COI*) line is also shown on Figure 1.

Figure 1 illustrates the larger cost savings due to perfect information for projects for which little or no prior information or experience exists. This has been shown as three lines. The upper *VPI* line assumes that very little prior information exists to guide the bidders, such as in a totally new channel, one that has never been deepened before. The intermediate *VPI* line is for a channel-deepening project where at least some prior

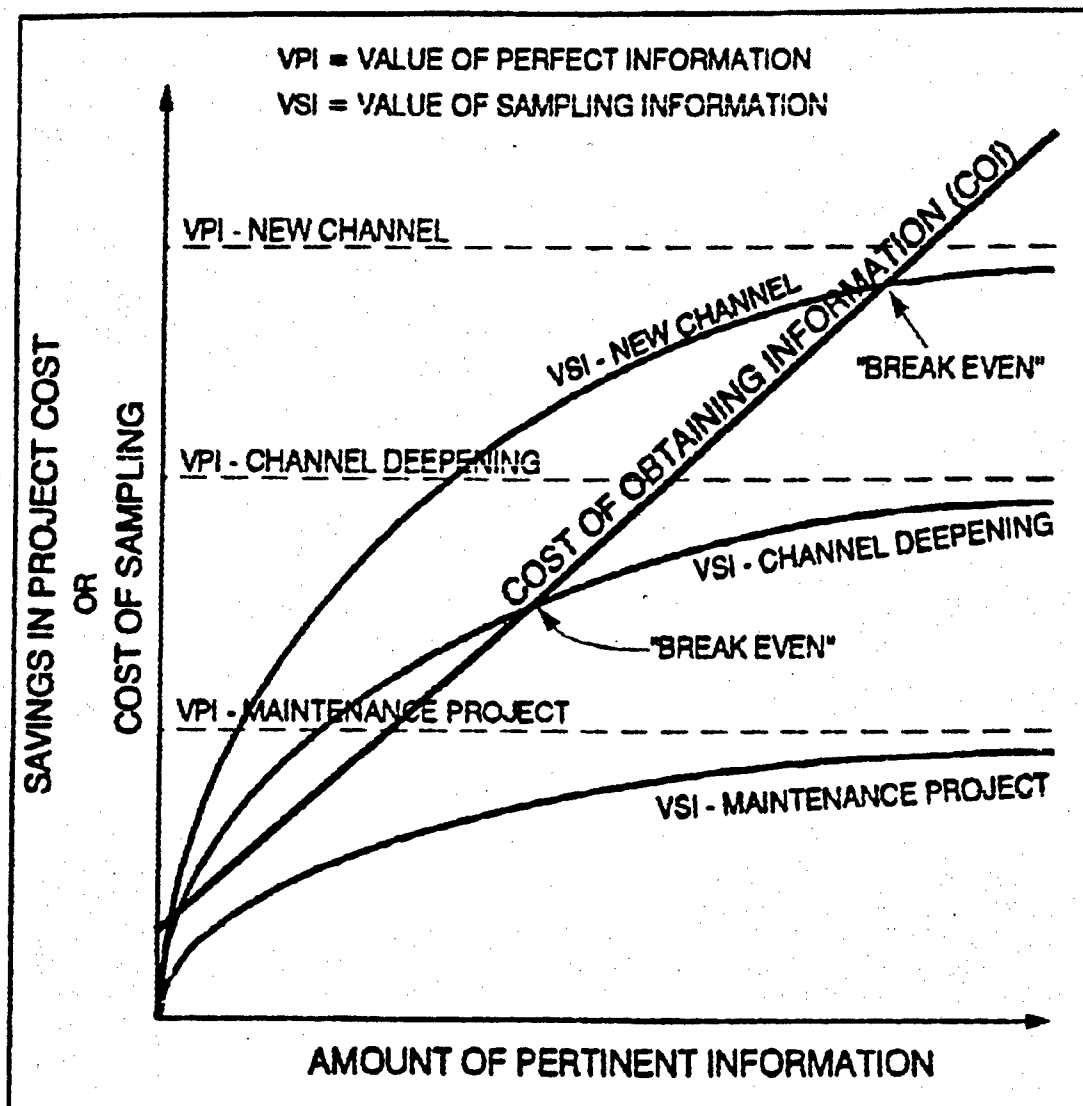


Figure 1. Value of additional subsurface information

information exists because of a previous channel-deepening project. The lowermost VPI line is for a maintenance project on which much prior information exists. The magnitude of the ordinate and the slope of the COI (cost) line is arbitrary in Figure 1 and can be controlled somewhat by the type, method, and sequence of the investigation.

The three types of projects shown on Figure 1 each have a different *optimum* or *break even* point, i.e., the amount of geotechnical information above which the cost of obtaining more information is greater than its value in reducing the project costs. Below that point, the savings to the project, the VSI, is greater than the COI. In the figure, the VSI curve for a *fictitious* maintenance project is shown completely below the COI line. This illustrative example shows that, in some situations such as

well-documented and experienced, stable maintenance projects, pre-existing geotechnical knowledge is *sufficient* and no amount of site investigation will likely contribute to a reduction in project costs. In these types of situations, therefore, no site investigation is justified. The relationships shown in Figure 1 will vary from project to project as the complexity of the soil profile changes.

The amount of time, money, and effort that should be expended in a site investigation is, ideally, that which will match the savings in project cost due to the availability of the information, as shown in Figure 1. This is the point of *sufficiency*, the "break even" point, and its interpretation is a matter of calculation—*provided the information for the calculation is available!* Unfortunately, it is virtually impossible to obtain the amount of information needed with presently available cost accounting systems. In the absence of known values of probability to be used in Bayes' Theorem, personal intuition, biases, and fear of risk (personal utility factors) must be used to establish the point of sufficiency. The point of sufficiency will not be the same for all groups involved, the owner, the engineers, the contractors, because all have different perceptions of the *utility* of money, i.e., personal utility factors.

Utility factors differ between (a) the owner's organization, which is intent on reducing total job cost, (b) the geotechnical and other engineers, who are risking their professional reputations, and (c) the dredging contractors, who are bidding and risking money on the proposed project. Therefore, there can be no universally defined magnitude of a subsurface investigation strategy, or plan, for a specific project. No matter what the scope of the investigation, someone or some organization, with a different personal utility, or level of acceptable risk, will have a different VPI and different VSI and COI curves from everyone else.

A good consensus approximation to Figure 1 can be obtained from frank, detailed discussions between project planners, estimators, geotechnical engineers, and the dredging contractors expected to bid on the project. All of their individual intuitions and biases, and utility factors, can therefore be brought to bear in establishing their personal evaluations of the prior probabilities used in Bayes' Theorem, whether they recognize them as such or not. This procedure is presented and discussed in many business management texts, such as Spurr and Bonini (1967). In this manner, by open and concerned discussion, a scope of work for the subsurface investigation can be reached that is satisfactory, or at least acceptable, to all parties. Details of the specific procedures for the site investigation can then be developed by the geotechnical engineers to satisfy the needs of the group decision.

Question 3: Significant Geotechnical Properties

Spigolon (1993a, b) discussed the properties of a sediment that are significant to dredging operations. They are the properties that will assist in the evaluation of the sediment's excavatability, transportability, and disposability. The descriptor terms used for each significant property may be (a) general, or (b) based on a classification system. The two major dredging-related soil classification systems in use are the USCS (American Society for Testing and Materials (ASTM) 1993) and the Permanent International Association of Navigation Congresses (PIANC 1984) system. Most general, or generic, descriptors are defined in terms of one or another of the classification systems.

A complete phrase to describe a sample of soil sediment to be dredged should contain at least the following terms (Spigolon 1993a):

- a. In situ shear strength—relative density (compactness) of cohesionless soils; relative consistency of cohesive soils; degree of cementation of cemented soils.
- b. Grain size distribution of the soil.
 - (1) Maximum grain size.
 - (2) Median grain size (for hydraulic pipeline pumpability).
 - (3) Modifiers to the principal soil type to indicate the uniformity and shape of the gradation curve.
- c. Plasticity of the -No. 40 screen fraction (liquid and plastic limits, plasticity index).
- d. Grain shape and hardness (coarse-grained soils only).
- e. In situ water content of cohesive soils (as cross-check on strength tests).
- f. Color (for stratum continuity and possibility of organics) and odor (if any).
- g. Presence and estimated amount of peat, other organics, cementation, shells, and debris.

In addition, the following information is often of importance and may be reported separately:

- a. Rheologic properties of slurry at various densities (to indicate energy requirements in a pipeline).

- b. Sedimentation rate in salty water (to indicate settlement rate of fine-grained fraction in hopper or in disposal area).
- c. Bulking factor (to indicate volumes needed in a hopper, barge, or disposal area for a given volume of excavated sediment).

Question 4: Subsurface Investigation Strategy

A geotechnical subsurface investigation for a dredging project must answer several questions:

- a. How many soil and rock deposits are there within the proposed dredging prism? Where are they located and what is their configuration?
- b. What kind of material does each deposit consist of? What are the average values and the range in values of each sediment property?
- c. Are the deposits homogeneous? Do the significant properties trend in a known, or predictable, manner along the width, length, or depth of the dredging prism?

Strategy, or plan, for a subsurface investigation

The procedure for a typical geotechnical subbottom investigation for a dredging project contains the following steps, as shown in Figure 2.

- a. A review is made of all available prior (existing) information—the geologic literature, both published and unpublished, records of previous geotechnical studies in the project area, and personal experiences with soils in the project area. This is sometimes called a literature review or a desk study.
- b. Based on the prior information, an initial hypothesis of the geotechnical subbottom profile is developed, including the types, configuration, and geotechnical character of the subbottom soils present.
- c. If the available information is *sufficient* (see Spigolon (1993b) for a discussion of sufficiency) for the project, the site investigation is terminated at this point. If it is not sufficient, then an estimate is made of site variability. If the site is known, from extensive prior information, to be fairly uniform or to vary in a known manner, a site exploration plan is developed (step *f.* below). If the site variability is not well-known, then a geophysical survey may be appropriate.

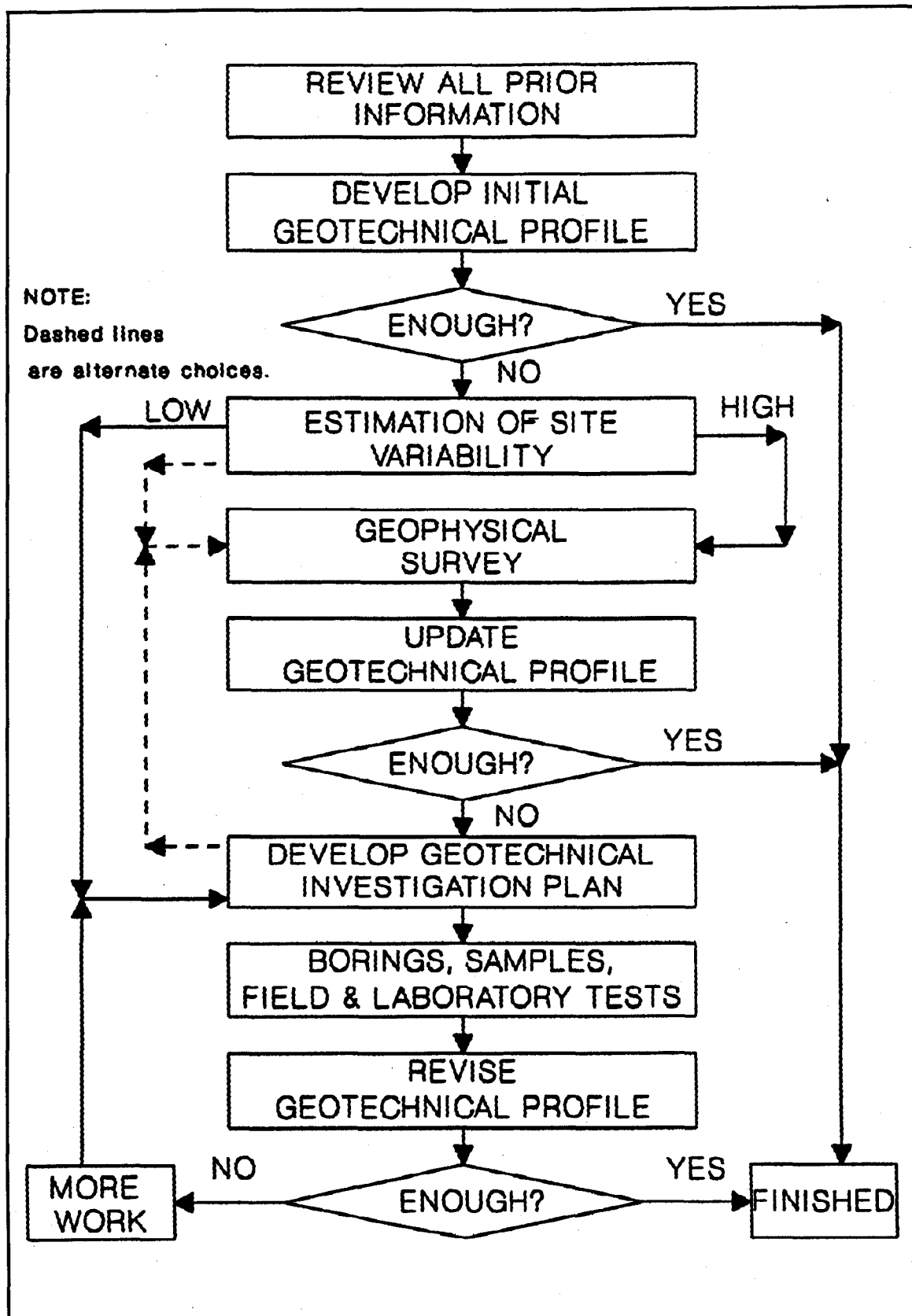


Figure 2. Flow diagram for a dredging subsurface investigation

- d. Where appropriate, continuous subbottom information is obtained by geophysical studies using acoustic subbottom profiling or other suitable method. The requirements for ground truth sampling and testing for correlation with the data are established.
- e. Geophysical data are used to amend the initial hypothesis of the soil profile. If the updated geotechnical information is now sufficient for the project, the site investigation is terminated.
- f. If the amended subsurface profile estimate is still not sufficient, then a geotechnical physical site exploration plan is formulated. The number and location of the test sites will be dictated by site variability (Wu 1989).
- g. At each exploration site, specific depths and specific methods are selected for sampling and testing the subbottom materials. Sampling depth may be reached by drilling or the digging of pits. Geotechnical field tests are made and samples are obtained for laboratory tests. Identification tests are made on the soil samples at the site using field-expedient methods and later confirmed in the laboratory or office. A description, and perhaps a classification, is made for each sample.
- h. The new geotechnical information is summarized and added to the existing information. The previous subsurface profile estimate is reviewed for consistency with the new data and the estimated subbottom profile is revised as needed.
- i. If the revised subbottom profile estimate is now sufficient for the project, the subsurface investigation is terminated. However, if more information is required, then additional geophysical and/or geotechnical sampling and testing are done. This iteration is continued until a point of sufficiency is reached (Spigolon 1993b).

Preliminary studies using geophysical methods

The use of geophysical survey methods as part of the preliminary studies for a subsurface investigation plan has the potential of resolving a major factor in the causes that lead to differing site conditions claims. If only borings and/or pits are made for a subsurface investigation, sediment characteristics and stratification between the point sources must be extrapolated, and often guessed at. In new work dredging, rock is 50 or more times more costly than sand to excavate and remove. Differences in quantities, especially in the case of discontinuous rock surfaces *within* the dredging prism, can lead and have led to (a) higher than necessary bids because of uncertainty of the exact volumes and locations, and (b) unexpected and costly claims.

The value of geophysical surveys was stated in a Naval Facilities Engineering Command (NAVFAC) manual: "In contrast to borings, geophysical surveys explore large areas rapidly and economically. They indicate *average* conditions along an alignment or in an area rather than along a restricted vertical line at a single location as in a boring. This helps detect irregularities of bedrock surface and interface between strata." (NAVFAC 1982). Therefore, although geophysical information is not, by itself, as precise as boring data, geophysical methods are complimentary to the boring and/or test pit information.

WES acoustic impedance geophysical survey system

Ballard and others at WES have developed a system for acoustic impedance subbottom profiling (Harmon and Ballard 1991; Ballard et al. 1993; McGee, Ballard, and Caulfield, in preparation). This is one of the relatively new geophysical survey methods that have the potential of being of great value in dredging subsurface investigations, particularly for providing preliminary subsurface profile information. Because dredging is typically done on underwater sediments, *acoustic subbottom profiling* from a boat provides a rapid, economical, and effective geophysical method of obtaining general information about the site *before* any boring, test pit, or probing locations are planned.

Geophysical techniques use two sources for the measurement of energy fields in the earth: (a) existing, or passive, earth fields, such as gravimetric, electric, magnetic, thermometric, and nuclear, and (b) deliberately induced, or active, fields, such as seismic, acoustic, electric, electromagnetic, and nuclear. Because of the need to measure subbottom characteristics through water, the induced acoustic impedance method seems to be the most practical and useful (Harmon and Ballard 1991), although electric resistivity also has some promise.

As stated by Ballard et al. (1993): "The acoustic impedance method is a modification of the seismic reflection technique commonly used in offshore oil exploration but tailored to shallow-water environments." In this method, sound energy is emitted from an acoustic source, at or below the water surface. As the energy arrives at a boundary between two layers of different material properties, "part of the energy will be reflected back toward the surface and part transmitted downward." The receiving system is also in the water, attached to a small boat.

Some of the transmitted energy will undergo absorption or attenuation in the layer while the remainder is transmitted to the next stratigraphic boundary. The time for a signal to be transmitted and reflected, from a stratigraphic boundary, along with knowledge of the type of material, i.e., the sound wave velocity, is used to determine the thickness of the layer. Ratios between transmitted and reflected energy are dependent on the density and the sound wave velocity of the materials through which the energy is moving. Energy loss is a function of the frequency of the sound

wave. *Acoustic impedance* is the product of transmission velocity (centimeters per second) and the density of the material (grams per cubic centimeter). By use of two or more frequencies simultaneously, *both* the stratigraphic boundary and the type of material can be estimated.

The acoustic impedance has been determined for a large number of sediment materials empirically. This was done because certain assumptions must be made about attenuation factors and these require that site-specific borings, or "ground truth," be made to calibrate the system.

The acoustic impedance system developed at WES consists of two commercially available instruments, a 3.5-kHz "pinger" system and an integrated, high definition 400-Hz to 5.0-kHz "boomer" system. Reflected signals are picked up, amplified, filtered, and recorded with a specially designed digital data acquisition system. By extension of the ship-board equipment to include Global Positioning System devices, the system can also detect the depth of the bottom and record it with a corresponding location. In this manner, a fully three-dimensional estimate of the sediment profile of the proposed dredging prism can be established.

As concluded by Ballard et al. (1993): "Results from properly calibrated [geophysical] surveys have been used to provide Corps Districts and dredging contractors with:

- Density estimates of marine sediments. ("Estimates of in situ density are derived from computed impedance values and correlated with ground truth information.")
- Continuous subbottom information for planning and designing dredging and sampling programs.
- Estimates of the volume and type of material to be removed through dredging.
- A detailed and continuous geologic database for aiding long-term planning of future work."

Question 5: Locations of Exploration Sites

If the subsurface investigation is to be effective and cost-efficient, the locations of the total number of exploration sites along the length of a project depend on prior knowledge of the nature, distribution, and variability of significant properties of the sediments in the dredging prism. If borings or pits are made, as they often are, on an arbitrary spacing along the length and width of a dredging project site, then the more uniform

areas may contain more borings than necessary for sufficiency and the more complex areas may contain too few.

Mathematical statistics methods can be used to quantitatively establish the relative numbers to be distributed to each area according to the statistical variance of any one, or a group, of significant sediment properties. Alternately, because statistical variance is probably not known in advance, the distribution of exploration sites can be made on an intuitive evaluation of site variability. In the extreme case, if an area or volume of sediment is highly variable, then only enough exploration sites should be used to establish the complexity of the deposit since no practical number of borings or pits can determine the true nature of all parts of the deposit.

The distribution of borings across the width of the dredging prism also depends on the variation of the sediment properties. In a river, the sediments in a straight reach tend to have the same characteristics across the width. However, at any bend, the coarser materials settle out in the inside of the bend because water velocity is less there than at the outside of the bend. Similarly, sediment-laden waters entering an estuary will have a unique deposition pattern that depends on water velocity and the configuration of the water body. These factors must be recognized when allocating boring locations.

Question 6: Determination of Sediment Properties

The significant sediment properties, defined above, must be measured in some manner and the results of the measurements recorded and reported. Significant dredgeability properties fall into two groups: (1) the shear strength of the unexcavated, undisturbed in situ sediment, and (2) the characteristics of the excavated, disturbed sediment material. The first grouping, shear strength, affects the excavatability of the sediment. The second set of properties, those of the material irrespective of its original mass properties, affect the removability, transportability, and deposition behavior of the sediment.

Sediment property measurement methods also fall into two groups: (1) direct measurement of the significant properties of a sample, either undisturbed or disturbed, and (2) indirect measurements. Indirect measurements may be (a) measures of energy absorption by the undisturbed (natural state) material, or (b) correlations of the results of simple laboratory, or field expedient, index tests with more involved, more complicated, engineering behavior test results.

The energy to cause shear failure of a sediment can be directly or indirectly related to energy absorption during various tests. These include procedures such as the following:

- a. The acoustic impedance geophysical method (Harmon and Ballard 1991; Ballard et al. 1993; McGee, Ballard, and Caulfield, in preparation).
- b. Several in situ soil strength tests, such as the Standard Penetration Test (SPT), the Static Cone Penetration Test (CPT), the Vane Shear Test (VST), and others (Spigolon 1993b; Spigolon and Bakeer, in preparation (b), (e), (f)).
- c. Methods for rapid field indication of the compressive strength of rock using the DPR or the point load tester (Smith 1991a, 1991b).

Rapidly and easily obtained index properties, used to estimate the engineering behavior of soils, have been discussed extensively in almost every geotechnical engineering textbook. Much of this information was summarized by Spigolon (1993b). Spigolon also discussed methods for obtaining samples of soil sediments for laboratory or field expedient index properties tests. A relatively inexpensive method for obtaining continuous, disturbed, shallow samples of soils is by use of a vibrating tube sampling device (Smith and Clausner 1993).

All of these geotechnical engineering contributions to more effective, more efficient dredging subsurface investigations by the DRP are discussed below.

Acoustic Impedance studies

Planning of the appropriate and most efficient methods and equipment for sediment sampling and testing requires a foreknowledge, or at least a good estimate, of the stratification and type of material present at each proposed exploration site. Acoustic impedance subbottom profiling, discussed above, can provide the needed information. As described previously (Ballard et al. 1993), acoustic impedance survey results include layer thicknesses, the general type of soil material in each layer, and the estimated density of each layer. Soil density has been used in the dredging estimating program presently being used by the Corps of Engineers, as discussed in Chapter 2 of this report.

For a soil of given composition, an increase in soil packing (increase in dry density or decrease in void ratio) is typically accompanied by an increase in strength and a decrease in both compressibility and permeability. However, the density of a soil is itself not a direct indicator of strength, since soils of the same density can have widely different dredgeability properties.

The shear strength of clean granular soil, gravel and/or sand, is a direct function of the soil's density *relative* to its laboratory-derived maximum and minimum density. The magnitude of the maximum and minimum density values, and therefore the range of in situ densities, for any clean sand

are independent of particle size. Burmister (1948, 1964) and others have reported that the particle size range (coefficient of uniformity, $C_u = d_{60}/d_{10}$) has the *most important* effect on the maximum and minimum densities. Other factors include variances in the shape of the gradation curve (S-shaped, linear, concave, or convex), and particle shape (roundness, angularity). For the normal range of uniformity coefficients found in sediments, both the maximum density and the minimum density may range over 3 to 5 kN/m³ (20 to 30 pcf) with the actual cohesionless soil density ranging between these values.

The shear strength of cohesive soils is related not only to the density (void ratio at failure), but to other factors including the stress history, structure (flocculated or dispersed), nature of the pore fluid, degree of saturation, conditions at the time of formation of the soil, mineralogy, and percent clay fraction (Whitman 1960).

GEOSITE expert system program

All of the soil sampling and testing methods that are applicable to determining the significant soil properties defined above were summarized in a DRP report (Spigolon 1993b). This information was later systematized by Spigolon and Bakeer (1993; in preparation (b), (c), (f)) in a personal computer expert system program called GEOSITE. GEOSITE provides computer-accessed guidance to geotechnical engineers, engineering geologists, and others in the selection of sampling and testing equipment *for use at a single geotechnical exploration site* during a subsurface investigation for a dredging project.

Expert systems are computer programs capable of providing the necessary vehicle for recording the accumulated knowledge and experiences of experts, in any specific discipline, in a knowledge base and providing for interaction between the user and the knowledge base. Inexperienced personnel can learn from the guidance program. Also, knowledgeable and experienced personnel can benefit from consultation with their peers for review and as a check of their own work.

The knowledge base of GEOSITE contains a database of rules and a series of IF - THEN rule statements that include all of the questions a typical user may ask. The rules can incorporate and process judgement, experience, empirical rules of thumb, intuition, and other expertise as well as proven functional relationships and experimental evidence.

The flow of GEOSITE starts with the user's indication of the *type of sediment* expected to be found in any one layer at a given exploration site. This knowledge may come from a geologic literature review and/or from an acoustic impedance survey. The GEOSITE expert system then answers the Sampling Query, which is posed to the knowledge base, as: "IF the sediment type is . . . , THEN the suitable sampling devices are" by displaying all suitable sampling methods for that sediment type.

The user then indicates one of the suitable sampling devices and GEOSITE answers the Testing Query, posed to the knowledge base as: "IF the sediment type is . . . , AND the sampling device is . . . , THEN the suitable testing methods are" Since there are usually several suitable testing methods for each combination of sediment type and sampling device, each combination is assigned a confidence factor and a utility factor. A *confidence factor* is defined as the relative accuracy and precision of a strength testing method compared to all of the other suitable methods. A *utility factor* is defined as the relative efficiency of a testing device in terms of time and money cost, including difficulty of mobilization of equipment at the site, time for making a test, complexity of test method, and need for securing a sample using a different device, compared to all of the other suitable methods.

GEOSITE permits the user to compare, for a given sediment type, several combinations of sampling device and testing method by simply repeating the rapid Sampling Query and Testing Query. If desired, a computer printout of the results of the Testing Query can be made for each desired combination of sediment type and sampling device.

The GEOSITE expert system program then proceeds to give guidance on the selection of suitable methods for reaching sampling and/or testing depth, including methods for making borings, test pits, and probings. Work platforms suitable for supporting personnel and equipment for various conditions are recommended. Finally, those material properties tests that are appropriate for each sediment type, to define significant properties, are presented.

Recognizing that the simple presentation of guidance in a table on a computer screen will not be sufficient for most users, the *Discussion* (help) topics section of the program is available from any of the screen displays, at any point in the program. The Discussion section contains a number of encyclopedia-like short discussions of all of the various topics covered in the several queries. Much of the information was derived from the published site investigation strategy report by Spigolon (1993b) and from other sources. The expert system program, therefore, provides a rapid, easily accessed method for obtaining expert guidance on selecting sediment sampling and testing methods, and on methods for accessing the sampling/testing depth. The expert system serves as a guidance tool for inexperienced persons and as peer review for more experienced workers.

Inexpensive vibracoring sampling device

The shear strength of the sediment to be excavated must be known, usually from direct measurements. In the case of maintenance dredging, where the strength of the newly shoaled material is relatively consistent from dredging to dredging, the excavatability can be reasonably estimated from project records. In those cases, only a sample of the material, without strength tests, is sufficient for the laboratory measurement of the

material (grain) properties of the newly placed sediment. The same continuous sample can be used for chemical tests, if required. If the strength of the in situ soil is also needed, as it would be in new work investigations, the vibrating tube sampler can be coupled with close-by probing with a device such as the CPT device or the dynamic, solid cone test device, which do not obtain samples.

One of the more useful devices for obtaining samples of unconsolidated sands and fines is the vibrating tube corer. This type of device has been in use for obtaining continuous disturbed, but representative samples of cohesionless and fine-grained sediments on land and in shallow water for over 30 years. Such devices are relatively light in weight, relatively inexpensive, and can be handled in a small boat by a crew of two or three men.

There are several manufacturers of vibrating tube sampling devices worldwide. As a typical example of vibrating tube samplers, one proprietary device uses high-frequency (7,000 to 12,000 vibrations per minute) and low-amplitude vibrations applied to the drill string to shear the soils in the immediate vicinity of the cutting edge of the core barrel. This permits the device to enter unconsolidated granular and cohesive deposits at rates up to 1.5 m (5 ft) per minute. The specific proprietary equipment being described is lightweight, having a 39-kg (85-lb) engine, an 11-kg (25-lb) drive head, and lightweight tubes with diameters of 85 mm and 135 mm (3.35 and 5.31 in.), and is portable and operable by a two-person crew from a floating or fixed platform.

These devices impart a sample disturbance to the soil whose magnitude depends on the effect of the vibration, the side friction in the tube, and the vertical stability of the tube during penetration. It would appear logical that the rate of penetration of a vibrating tube sampler be related to the compactness (relative density) of a cohesionless soil and/or the relative consistency of a cohesive soil. Babcock and Miller (1972) reported good results in field tests to relate the rate of a vibrating tube sampler penetration to the SPT N-values for sand.

Smith and Clausner (1993) described the development and use of an inexpensive, shop-made vibrating tube sampling device. The cost of the power source, vibrator cable, and vibrator was less than \$1,000 (1993 prices). The system uses 30-ft sections of aluminum irrigation pipe with 1.6-mm (1/16-in.) wall thickness. The pipe is cut to the desired length, for the desired full length of the sample plus water depth plus about 0.6 m (2 ft) for the top of the tube to extend above water. A standard concrete vibrator is then attached to the top of the sampling tube and powered by a lightweight 5-hp, four-cycle engine. In cohesionless soils, a sample retainer is used at the bottom end of the tube. The entire tube and vibrator are then hoisted with a boat-supported A-frame and lowered to the bottom. Vibration is started and the device enters the soil, securing a continuous sample. The hoist is used to retrieve the sample tube. A bilge pump is used to remove all excess water from the top of the sample. Both ends of

the tube are sealed and the sample sent to the laboratory for the required material properties tests.

Rapid field tests of rock

It has been known for some time that it is more efficient to have a flexible subsurface investigation program, under the direct field supervision of a geotechnical engineer, so that the sampling and testing program can be modified as revelations of the subsurface investigation warrant rather than an inflexible one based on a working hypothesis of site conditions. Two contributions: (a) DPR improvements (Smith 1991a), and (b) point load test methods for weak rocks (Smith, H. 1990, 1991b) are aimed at permitting the geotechnical engineer a rapid evaluation of rock parameters, in the field, as the sampling and testing are proceeding.

Drilling Parameter Recorder. Refinements are being made at WES (Smith 1991a) on the DPR. This device has been used to characterize rock materials during the subsurface exploration borings. This device provides a continuous record of parameters related to the characteristics of a rock layer relative to depth. In the DPR system developed at WES under the DPR, the following parameters are measured and recorded continuously:

- a. Relative torque indicated by pressure to the hydraulic motor turning the drill string.
- b. Downthrust on the drill bit.
- c. Rate of advance, or penetration speed.
- d. Rotation rate.
- e. Holdback pressure on the drill string.
- f. Time to drill one digitized increment of depth.

Numerical data from the several sensors are combined in an appropriate manner to give a combined-parameter estimate of the specific energy of drilling. Given adequate production records in the future, this information could be used to yield a continuous record that is related to, or correlated with, unconfined compressive strength (UCS) or other significant property. The relative strength of vertical reaches where poor or no core recovery would be possible can then be evaluated. And, the DPR parameters are also related to other factors that influence excavatability beside the UCS. The DPR can also record the location of discontinuities and stratum changes.

Point load test for soft rock. Contractor's claims for differing site conditions when dredging rock are often based on material strength changes. The strength characteristics of some rock, particularly soft sedimentary rock, depend on testing in in situ moisture conditions. This can be an important consideration during the initial subsurface investigation. Furthermore, the FAR Differing Site Conditions/Changed Conditions clause, part (b), states: "The Contracting Officer shall investigate the site conditions promptly after receiving the notice [of a differing site condition claim]." It is desirable during rock dredging projects, therefore, that a rapid, onsite method be available for assessing the strength of rock, particularly of rock pieces and broken cores.

The rock property commonly accepted for indicating strength, rippability, and dredgeability is UCS. The point load test of rock is an index test that correlates well with the UCS for igneous and hard sedimentary rocks. Now the correlation is being extended to the softer sedimentary rocks that are mechanically dredged in many coastal areas (Smith 1990, 1991a, 1991b, in preparation).

The test for UCS requires considerable time and effort. An intact core sample must be carefully taken in situ, usually with a diamond-tipped core barrel. The core must be carefully returned to the laboratory where the ends of the test specimen, with a length twice the diameter, must be sawn plane and the ends lapped. The specimen is then placed in a high-capacity compression testing machine and tested to failure. This implies a fairly large, heavy testing machine.

The point load tester is a portable compression testing device, typically having a capacity of 44.5 to 67 kN (10,000 to 15,000 lb) capable of testing high-strength rock using NX-size cores. Pressure is normally applied by a hydraulic ram. The sample is compressed between two platens, each having 60-deg conical points with a 5-mm point radius. Cored samples may be tested diametrically or axially, with no accurate sample preparation. Of greater importance is the fact that an irregular lump can be tested. It is suggested that several sample specimens be tested from the same deposit and the results averaged (Smith 1990).

Although fairly reliable correlations exist between the point load test and UCS for igneous and hard sedimentary rock, the same is not true for soft sedimentary rock. As a result, a DRP study was carried out by Smith (1991a,b) to collect a database of test data for soft/saturated rock called The Point Load Index and Unconfined Compressive Strength Data Base System (PLUCS). The PLUCS database, in 1991, contained results from over 400 rock tests from 10 different material sources. As described by Smith (1991a,b):

Correlation of point load index with UCS is material-type dependent, and such correlations are ideally based on a site study. . . . The use of previously published hard rock information to estimate UCS for weaker/saturated materials can easily yield results in error by a factor

of two. The PLUCS provides data for material-specific correlations based on tests performed on both dredged material and on other saturated rock materials selected for uniformity. . . .

In summary, the advantages of the point load test, its application to dredging operations, and its application to soft rock testing, either during the initial subsurface investigation or for rapid assessment of rock strength in the field as the result of a claim are:

- a. The point load test is rapid, the testing machine is portable, and the test can be made in the field.
- b. Sample specimen preparation in the manner of the UCS is not necessary. A short core specimen or a lump of rock can be tested.
- c. During the initial dredging exploration, sample specimens can be tested in the in situ saturated condition, improving the value of the strength test. The usual precautions for handling and storage of all the samples are eliminated.
- d. The point load test is inexpensive relative to the UCS. The potential for cost savings exists because either (a) the total number of expensive, laboratory UCS tests can be reduced, or (b) a larger total number of test measurements of rock strength can be made for the same cost, improving the amount of information available from the exploration.
- e. Claimed changes in material type can be tested immediately, in the field, permitting onsite decisions about the validity of the claim. A costly and time-consuming claim evaluation process, for both the owner and the contractor, is more likely to be avoided by onsite evaluation of rock strength.

Question 7: Methods for Accessing Sampling and Testing Depth

Except for the inexpensive vibrating tube sampler described above (Smith and Clausner 1993), the DRP did not develop any new or improved methods for making borings, test pits, or probings. It did, however, present a summary discussion of this topic in the "Site Investigation Strategy" report (Spigolon 1993b). The information contained in that report, and in other published literature, about sample/test depth accessing methods was incorporated in the expert system computer program GEOSITE, described earlier in this report. It is expected that the summarized information will provide sufficient guidance to inexperienced engineers, or peer review to experienced ones, to cause a more cost-efficient and effective subsurface investigation to be carried out.

The GEOSITE computer program (Spigolon and Bakeer, in preparation (b), (e), (f)) recommends that consideration be given to the cost of mobilizing and moving the accessing method (boring, pit, or probe), and the necessary work platform, as part of the overall cost for planning a subsurface investigation. The overall system must be optimized as a means of getting the most useful information about the subbottom materials in the proposed dredging prism for the allocated funds (how to get the most "bang" for the "buck"). This means that the cost of each combination of suitable sampling devices, suitable strength testing methods, suitable accessing methods, needed work platforms, and the mobilization and movement costs for personnel and equipment, must all be combined into an overall investigation cost. The GEOSITE expert system computer program, while not designed to compute costs, provides a means for rapidly determining the expert-derived suitability of each component of the system for the sediment types expected to be present.

4 Other DRP Contributions to Reducing Causes of Claims

In addition to its contributions to improving subsurface investigations, the DRP has made other contributions to reducing the impact of differing site conditions claims. The contributions include:

- a.* Improved understanding of subsurface investigation terms by means of a report on dredgeability descriptors and an expert system computer program that correlates geotechnical information with dredgeability.
- b.* A report of an investigation to determine the geotechnical properties of soils that lead to the existence of clay balls in a hydraulic pipeline.
- c.* Improvements in the capability of the Corps of Engineers to evaluate the contractor's project work. These include reports of several ongoing studies that include a method for automatically recording contractor operations and improvements in horizontal and vertical measurements of dredge location.

Understanding Dredgeability Terminology and Processes

The lack of precise communication can cause misunderstandings between the owner (the Corps of Engineers) and the contractor in dredging contracts and result in claims that might have been avoided. Geotechnical engineers, geologists, environmental engineers, biologists, estimators, dredging equipment manufacturers, and dredging contractor personnel have their own methods for describing sediments. These groups do not fully agree on a common system for characterizing and describing sediment properties and, therefore, often misinterpret sediment descriptions.

A PIANC soil classification report states the following:

"It is . . . essential, in the dredging industry, that all those having to communicate information on soils and rocks should employ the same technical language. This calls for a uniform system of classification, particularly at the international level, so as to obviate any misunderstanding."

Subsurface investigations for dredging projects are normally made under the direct supervision of geotechnical engineers. Written and graphical descriptions of the subbottom sediment profile will invariably be made and reported using geotechnical engineering methods and terminology.

The relationship between the dredgeability properties of the materials encountered and the geotechnical engineering description of the soil properties, therefore, needs to be clearly understood by all parties to a dredging project. This includes the geotechnical engineers, the government's estimators and project administrators, and the contractor's estimators and operations personnel.

Descriptor report

A report was prepared (Spigolon 1993a) in response to a work unit directive to develop standard dredging-related descriptors. A similar report was prepared by Dunlap (1993) in which descriptors being used in the European dredging industry were discussed. The desired technical approach to this topic was given by Calhoun et al. (1986):

"The methods of observation and the descriptors now used represent a mixture adopted (sometimes not adapted) from diverse fields such as environmental engineering, geology, soil mechanics and foundation engineering. Descriptors need to be developed such that engineering properties are either directly given or can be readily inferred for engineering applications such as dredgeability prediction. The term 'dredgeability' is given to mean the ability to excavate underwater with respect to known or assumed equipment, methods, and in situ material characteristics."

For purposes of the descriptor study and report (Spigolon 1993a), the definition of *dredgeability* quoted above was modified to encompass the effect of sediment properties on the entire dredging process:

"The term 'dredgeability' is given to mean the ability to excavate underwater, remove to the surface, transport, and deposit sediments with respect to known or assumed equipment, methods, and in situ material characteristics."

The descriptor report was intended to serve as a common base of nomenclature and definitions for use by all readers. The report contained a detailed discussion of the following:

- a. Dredgeability properties of soils that govern dredging equipment selection and performance.
- b. Geotechnical soil properties (discussed above in this report) that are significant for indicating, or inferring, the dredgeability properties.
- c. Standard terms and definitions for the significant geotechnical engineering soil properties that are used as descriptors.

An understanding of dredgeability descriptors requires an understanding of dredging processes and how sediment properties affect them. Dredging is typically conducted in three stages:

- (1) *Excavation*—loosening or dislodgement of individual material grains or of a cohesive group of particles from the in situ state. Excavation mechanisms include: (a) direct suction, (b) hydraulic or pneumatic erosion (scour), (c) mechanical cutting, and (d) mechanical scooping.
- (2) *Removal and transport*—removing the sediment from the bottom to the surface, and transporting the material to a disposal site by means of (a) a hydraulic slurry pipeline, or (b) mechanical containers.
- (3) *Disposal*—deposition of the material on land or into a water disposal area by means of the hydraulic or mechanical transport system. In some instances the deposited material may be needed for such purposes as compacted fill or beach nourishment.

Sediment properties affecting excavation. *Direct suction* will only work if the sediment is fine-grained and is extremely soft and plastic, i.e., grain-to-grain friction does not occur. *Scour* (erosion) is inhibited by the inter-particle attractive forces of cohesion found in clayey soils. The energy to cause scour is also affected by particle size; the easiest particles to scour are fine sands and silts. *Cutting* or plowing are usually done with very little overburden. If the sediment is cohesionless, the normal force on the shear plane is very low and shearing resistance is then a function of the pore water pressure, which is a function of permeability, which, in turn, is a function of grain size distribution, of the relative packing of the grains, and the speed of cutting. *Scooping*, or digging, usually involves a deeper shearing action than cutting; therefore, the normal force increases the shearing resistance, as does the grain size. In both cutting and scooping, cohesive soils and rock are not affected by overburden pressure, only by cohesion, which is related to consistency. For rock, the blasting and/or ripping characteristics are directly related to strength. Adhesion of the

soil to the cutting surface, whether cutting or scooping, depends on the soil type, its liquidity, the type and roughness of the cutting surface, and the pressure of the sediment against the cutting surface (normal force). *Turbidity* occurs around a cutterhead, draghead, or scoop during excavation or during water disposal. The sedimentation rate of grains varies inversely as the square of the diameter, the smaller grains settling much more slowly than large ones. Large grains, such as rock fragments, gravel, and coarse sand will settle in a matter of minutes. Friable silts and clayey silts will remain in suspension for hours and even days, especially in turbulent water.

Soil properties significant for evaluating the excavation dredgeability of sediments are (a) in situ shear strength, (b) overall grain size distribution, (c) angularity of coarse grains, and (d) plasticity of the fines. In the case of rock, grain size distribution and angularity of the blasted or ripped rock fragments are significant factors.

Sediment characteristics affecting removal, transport, and deposition. *Pumpability* of a sediment is a function of median size, grain shape, and organic content. The maximum size of particle determines the required pump clearance. The rheologic behavior of the slurry depends on slurry density and "mud" (fines) content. The *abrasiveness* of the sediment on the pipeline and pump parts is related to the angularity and hardness of the grains and on the grain sizes present. The potential for degrading *clay balls* in the pipeline is a function of the amount of fines present, on the in situ density, and on the amount and type of clay minerals, which determine the plasticity of the clay. *Sedimentation rate* and *bulking* in a hopper or other slurry bulk transport are determined by the grain size distribution and plasticity of the fines. The *stickiness* of a clayey soil to the metal surface of a scoop depends on the plasticity of the soil and its wetness. The *dumpability* of a sediment from a mechanical transport, such as a hopper or barge or truck, depends on its stickiness and/or its tendency to arch. *Bulking* in the disposal area depends on grain size distribution, plasticity of fines, slurry concentration, and in situ density. *Compactability* is also a function of grain size distribution and plasticity of fines.

Once the sediment is dislodged from the bottom, the undisturbed, in situ strength characteristics are destroyed and only the properties of the individual grains are of interest. Therefore, the properties that govern are (a) grain size distribution including the maximum size, median size, and amount of fines, (b) hardness and angularity of the grains, (c) plasticity of the fines, and (d) organic content. Each of these properties is explicitly defined in the USCS, ASTM (1993) Method D 2487, and its accompanying ASTM Method D 2488.

DREDGABL expert system program

A Knowledge-Based Expert System computer program titled "Geotechnical Factors in DREDGeABiLity" (DREDGABL) was developed (Spigolon and Bakeer 1993, in preparation (a), (c), (d)) to serve the dredging community as a computerized geotechnical engineering consultant. DREDGABL provides guidance in the suitability of various types of dredging equipment for specific sediment types whose properties are described in the contract documents. The theory of operation of expert systems was discussed earlier in this report in the discussion of GEODREDG.

DREDGABL is intended to serve as a geotechnical engineering expert, always available to interpret sample test and observation data for estimators and planners, whether Corps of Engineers or contractor, in terms of dredgeability. It can also demonstrate to the geotechnical engineers and geologists involved in a dredging project site investigation what the important sediment properties are for dredgeability evaluation (Spigolon 1993a).

It is assumed by DREDGABL that the user possesses a set of boring logs or a soil profile with the typical USCS or ASTM descriptors given for each stratum. In the present version, DREDGABL considers only one sediment type at a time in its evaluation of the suitability of various dredge types for that sediment.

The first question asked by DREDGABL is: "What is the general sediment type?" The computer screen used to pose the question includes the following choices:

- a. Gravel(USCS Classification gravel-series soils).
- b. Sand (USCS Classification sand-series soils).
- c. Fines (Fine grained soils: silt; clay; peat).
- d. Special (Rock, cemented soils, boulders, shells, fluid mud, etc.).

When a general sediment type is selected, the next screen asks: "What is the Main Name of the sediment?" Succeeding screens ask other questions about the appropriate soil properties, selected on each screen from a menu of possible answers to each soil properties question, until one of the following sequences has been defined:

- a. IF sediment type is: "Gravel"
OR sediment type is: "Sand"
AND name of the sediment is:
AND USCS classification is:
AND gradation fineness of the gravel or sand is:
AND relative compactness of a granular soil is:

AND grain angularity is:
THEN dredgeability conclusions are:

- b. IF sediment type is: "Fines"
AND name of the sediment is:
AND USCS classification is:
AND relative consistency of the inorganic or organic soil is:
OR liquidity index is:
AND plasticity index is:
THEN dredgeability conclusions are:
- c. IF sediment type is: "Special"
AND name of the sediment is:
THEN dredgeability conclusions are:

After all of the needed antecedents are requested and answered, an evaluation menu screen is then presented that contains the following choices:

- a. Hoppers (Suitability of hopper dredges).
- b. Pipeline (Suitability of pipeline dredges).
- c. Mechanical (Suitability of mechanical dredges).
- d. Disposal (Disposal area properties).

Following selection of any one of these topics, DREDGABL displays its evaluation of the suitability of generic dredge types, along with a brief explanation for each evaluation. The rules for evaluation operate internally in the expert system program to consider all of that sediment's known geotechnical properties that affect each of the specific dredgeability mechanisms. Depending on the choice, the screen displays conclusions about the suitability of the combination of sediment and dredge in terms of all of the dredgeability properties discussed above. Provision is made for a printout of the conclusions for any given set of sediment properties.

Clay Ball Degradation in Pipelines

Degradation of clay balls in a hydraulic pipeline can either be a serious problem or a desirable event. When a cutterhead or similar piece of dredging excavation equipment cuts a clay deposit, some clays enter the hydraulic removal and pipeline transport system as slivers, chunks, lumps, or clods (pieces). In some instances, the pieces of clay disintegrate and become part of a thickened slurry. In other cases, the pieces of clay tumble in the pipeline and become rounded into clay balls, which sometimes become armored with sand grains, shells, and other matter.

Clay balls existing in a pipeline can be a problem. The presence of the balls increases the energy needed to pump the materials. At bends, the balls will sometimes slow down and, under the pressure of the pumped water, may collide and coalesce into a larger mass, plugging the pipeline.

Conversely, the building of dikes in a disposal area using clay can be nearly impossible if the clay is slurried. If the clay can be deposited as clay balls, however, the mass can be made to stand on a flat, but reasonable dike slope. In this instance, it is necessary that the clay balls not degrade.

The basic mechanisms for degradation of clay balls are the subject of ongoing research at WES (in 1994). As an initial study, Richter and Leshchinsky (1994) investigated the soil properties needed by a clay to be conducive to the degradation of clay balls. A laboratory study was made using (a) clays of different plasticity (Atterberg limits) characteristics molded in a laboratory dynamic compactor to two levels of density. This implies two levels of initial shear strength. The resulting compaction-molded samples were machine tumbled, to simulate the action in the pipeline, and the degradation measured at intervals.

The results of the study, reported by Richter and Leshchinsky (1994), can be summarized as follows:

- a. For a clay with a plasticity index less than 25, continued tumbling will cause degradation into a slurry irrespective of the initial density (strength).
- b. For a clay with a plasticity index greater than 35, no reasonable amount of tumbling caused degradation, irrespective of initial density or strength.
- c. For a clay with a plasticity index between 25 and 35, continued tumbling caused degradation of the low-density (low-strength) specimens. The higher density (higher strength) specimens did not degrade materially under a reasonable amount of tumbling. Therefore, the initial density or strength of the clay pieces affects the degradation, or non-degradation, of clay balls only when the plasticity index is between about 25 and 35.

Then, using the Richter and Leshchinsky data as a tentative criterion, the Corps of Engineers and the dredging contractor can evaluate the likelihood of clay ball degradation, detrimentally or desirably, from any given clay deposit in the dredging prism from the results of a subsurface investigation *provided* the plasticity and in situ strength of the clay were determined or estimated.

Improving QA/QV Inspection Procedures

If there is a claim for differing site conditions, the Contracting Officer and the dredging contractor must be able to establish, and perhaps agree on, three measurable items: (1) exactly where the dredge was at any given time and exactly how deep it was digging; (2) the significant operating characteristics of the vessel and its equipment at that time; and (3) the dredgeability characteristics of the sediment being dredged at that time.

The first of these items, establishing horizontal and vertical location, has been the subject of six DRP studies. Enge and Pflieger (1992) investigated Differential Global Positioning System (DGPS) data link alternatives. Wells and Kleusberg (1992) discussed the feasibility of a kinematic DGPS. Geier, Loomis, and Kleusberg (1992) reported on a system analysis for a kinematic differential Global Positioning System.

Garcia (1990, 1992) presented a discussion of the application criteria and improvements for an automated system for real-time measurement of tide elevations. Grogg (1991) reported on the field evaluation of a commercial tide gauge.

The second item is the subject of an ongoing investigation at WES into the "Dredge Operations Silent Inspector System (DOSIS)." DOSIS was briefly described by Rosati (1990). Several formal reports also discuss the silent inspector, including Welp and Rosati (in preparation) and two reports by Cox (in preparation (a,b)).

The third item, sediment properties related to dredgeability, was discussed earlier in this chapter. The behavior of the dredge, and its productivity, are profoundly affected by the geotechnical characteristics of the sediment being dredged. Unfortunately, determination of dredgeability properties, in a measurable manner, cannot be done at present. The properties can only be estimated by extrapolation of subsurface investigation information.

Global Positioning System (GPS)

The Global Positioning System (GPS) was developed by the U. S. Department of Defense to simplify accurate navigation. The system is available to both military and civilian users. The system uses 21 satellites located 20,000 km (12,500 miles) above the earth and time periods of 12 hr. Three additional satellites are provided as spares. Signals are emitted from the satellites at known frequencies. The signals include an identifier and a timer. Typically, the user acquires the signal from four GPS satellites simultaneously. The timing signal from all four satellites is used to calculate the horizontal position of the user. Four separate and separated signals are needed to cancel out various biases and errors that are inherent in the system.

Wells and Kleusberg (1992) prepared a feasibility study report in March 1989, at a time when the GPS satellite system was not yet completed. Their report described both the absolute GPS and the DGPS, and the accuracies to be expected from each system. With the absolute, or conventional, GPS the accuracy of horizontal positioning ranges from 8 to 50 m (25 to 160 ft) for a stationary system. The differential GPS improves accuracy by measuring horizontal locations relative to, or differential from, a known location. This is done by establishing one of the four receivers at the known location and broadcasting the information from the fixed receiver to the vessel. In the DGPS, accuracy can reasonably be increased to 0.1 of the accuracy of the absolute values. The use of differential GPS permits the user to measure the vertical difference between the vessel and the fixed receiver station. This makes the GPS an invaluable aid in the accurate horizontal and vertical location of a dredge during excavation, transport, and deposition operations.

Enge and Pflieger (1992) investigated several types of broadcast systems for the transmission of DGPS signals from the fixed receiver location to the vessel. This was background work for later analysis and design of a working system.

Geier, Loomis, and Kleusberg (1992) reported a system analysis for a kinematic positioning system based on the GPS. Accuracy constraints on the proposed system were ± 10 cm (4 in.) vertical and ± 2 m (6.5 ft) horizontal. The result of the study was a decision matrix for selecting among a number of feasible equipment systems that would meet the accuracy constraints and other requirements.

Automatic tide gauges

The effect of tidal variations on the measurement of the depth of dredging using the water surface as the reference is self-evident. Tide gauges use pressure sensors to determine the depth, or height, of water at any time. Tide elevation data are recorded and, in some units, may be transmitted by radio for pickup by any interested user. Because of the electronic components involved in an underwater operating situation, reliability and accuracy of the gauges is of concern.

Grogg (1991) reported field evaluation tests of a commercial gauge of the type being used in several Corps of Engineers Districts. Although the tested gauges were reasonably accurate, several severe problems were encountered with the electronic components before and during field operation. Some of the equipment failures were traced to manufacturing and inspection practices by the supplier. Other problems occurred because of design details. Grogg recommended that "prospective Corps users verify the accuracy of individual gauges before using them for control of dredging operations."

Garcia (1990, 1992) described the Automated Real-Time Tidal Elevation System (ARTTES) for predicting tide elevation at a given location. Garcia first presented the application criteria for the system so that potential users may decide whether such a system is useful for a given dredging project. In the second document, Garcia reported improvements to give users access to ARTTES during inclement weather.

ARTTES uses a predictor-corrector technique for evaluating pressure sensor data. The water level sensor is connected to a VHF transmitter that is continuously broadcasting water level data. A VHF receiver is connected to a computer with ARTTES software "which predicts the tide level at a user-specified location based on data previously acquired within the designated area. The predicted water level is corrected for nontidal effects using data received . . . (Garcia 1990)" This system was developed to provide tide elevation data to nearshore, open-ocean areas up to approximately 20 miles offshore.

Silent Inspector system

The objective of DOSIS was stated by Rosati (1990):

"The U.S. Army Corps of Engineers depends almost completely on inspectors for quality control and performance monitoring of contract dredging. Automated inspection tools, referred to as 'silent inspectors,' are one way to assist inspectors, reduce the cost of responding to claims and make dredge production records more accessible, understandable, and usable. An effective automated dredge monitoring system can provide unbiased information to all parties involved in dredging activities."

Sensors distributed throughout the dredge vessel and equipment can be used to record significant data as a function of time of day. In DOSIS, data from all sensors are collected by a central data acquisition unit, a computer, and stored in a database in a specified manner. Data can be transmitted by VHF radio in real time, or the onboard data file can be stored on a diskette and physically transferred, to a shore-based facility for data manipulation, recording, and reporting (Welp and Rosati, in preparation; Cox, in preparation (a)).

Sensors will record most of the information now being recorded on data sheets by physically present inspectors and much more. The type of sensor data that is envisioned on a typical dredge will include, as examples only and not limited to, the following items measured concurrently and at nearly continuous time intervals:

- a. Project identification and sensor calibration data at the start of the project and at each subsequent calibration time.
- b. Vessel location, from DGPS or other locating equipment.

- c. Vessel downtime and/or travel time.
- d. For cutterhead dredges and similar equipment, the cutter location, speed, pump energy, and pump operating times. Length of pipeline, number and location of bends, pressure in the pipe at several locations, and the density (specific gravity) of the contained slurry, location and elevation of the discharge end.
- e. For hopper and similar type dredge, the type of draghead, its location, pump operation time, pump energy, vessel speed, density (specific gravity) of the slurry, weight of the material in the hold, water level in the hold, etc.
- f. For mechanical dredges, the boom position, the excavator horizontal and vertical position, excavator load, engine power, etc.

It is presently anticipated that each dredging contractor will be responsible for installing, operating, and maintaining the sensors and data acquisition system aboard the dredge (Welp and Rosati, in preparation; Cox, in preparation (a,b)). The requirements for each contractor's installation, the criteria for sensor capability, and the form of the database and database manager will be made part of the contract specifications. Much of the information requested by the DOSIS is presently being recorded by contractors for their own operations evaluation.

It is expected that such a system of monitoring the dredging contractor's operations will provide mutually acceptable information that will be of benefit to both the contractor and the Contracting Officer in the event of a differing site conditions claim. Although each system will be dredge-specific, both groups will be interpreting the same information, greatly reducing the unknown that often leads to disputes.

5 Summary and Recommendations

Summary of the Report

The DRP at the U. S. Army Engineer Waterways Experiment Station was a 7-year program started in 1987. One of the four mandates of the DRP was to reduce the impact of contract claims. This report applies the geotechnical engineering and other contributions of the DRP to understanding and reducing those factors that lead to contract claims regarding a difference in site conditions.

Factors leading to claims of differing site conditions

The summary statements made in this report were derived from four major sources. A review was made of the limited amount of published literature dealing with construction, and particularly dredging, contract claims. Telephone interviews were conducted with dredging contractors, dredging consultants, and Corps of Engineers geotechnical and dredging operations personnel. Several recent differing site conditions claims were reviewed. All pertinent documents published by WES for the DRP were studied, including DRP technical reports, technical notes, and information exchange bulletins.

Based on the literature search and interviews made for this report, it was concluded that two major factors contribute to differing site conditions claims: (1) lack of sufficient and effective communication about subsurface conditions between the owner (the Corps of Engineers) and dredging contractors, prospective or actual, and (2) lack of proficiency on the part of personnel, equipment, and/or procedures used by dredging contractors and/or the Corps of Engineers.

Contributions to more effective subsurface investigations

Several investigators have prepared research reports for the DRP dealing with geotechnical subsurface investigations. In a group of reports, members of the WES Geotechnical Laboratory presented a system for geophysical acoustic impedance surveys of subsurface sediments. The equipment is boat-borne and provides a rapid, relatively inexpensive overview of the location, areal distribution, density, and type of sediments in the proposed dredging prism.

WES reported the use of the DPR for obtaining a continuous record of a drill rig's response to a rock drilling effort. Another report discussed the use of the point load test as a means of rapidly measuring the strength of rock as an alternative to more expensive and time-consuming compressive strength tests of rock cores.

The development of a very inexpensive, shop-made vibrating tube device for obtaining samples from sands and fine-grained sediments in shallow water was reported. Vibracoring is a rapid and relatively simple way of obtaining continuous, representative, but disturbed samples. Continuous samples may prove to be of great value in, for example, environmental studies of sediments or in studies of recently shoaled maintenance material.

The geotechnical descriptors needed for defining soil properties during a subsurface investigation were the subject of a report. This was followed by a study of the factors involved in developing a subsurface investigation strategy, or plan. A knowledge-based expert system computer program was developed to provide guidance to geotechnical engineers and engineering geologists in the selection of suitable field sampling and testing methods for subsurface investigation at a single investigation site.

Contributions to increasing proficiency

Improved understanding of subsurface investigation terms is possible by means of two DRP products. A report discussed descriptors that may be used to indicate, or infer, the dredgeability of sediments (Spigolon 1993a). An expert system computer program that correlates geotechnical information with dredgeability was developed to provide ready guidance for dredging personnel (Spigolon and Bakeer 1994d).

Another report presented the results of an investigation to determine the geotechnical properties of soils that lead to the existence of clay balls in a hydraulic pipeline (Richter and Leshchinsky 1994). Clay balls can be a hindrance in a pipeline. Or, they can be a desired product if the objective is to build a dike using pumped clay.

Improved capability by the Corps of Engineers to evaluate the contractor's project work was the objective of several ongoing studies. The studies include a method for automatically recording dredge location and operations using a variety of passive instruments. Other studies include improvements in horizontal and vertical measurements of dredge location using a differential Global Positioning System and improvements in tide gauges.

Recommendations

The DRP has made a number of contributions to reducing the impact of contract claims regarding a difference in site conditions. As a result of the study described in this report, several recommendations can be made for immediate implementation. The recommendations are given in the following sections.

Improving communications between the owner and the contractor

Pre-construction conferences ("town hall meetings") between prospective contractors and Corps personnel should become a standard procedure in all dredging projects. There should be a continual interchange of information such as the following:

- a. Extent of the subsurface investigation.
- b. Probable effect of the findings of the subsurface investigation on dredging operations.
- c. Non-geotechnical site conditions, such as expected weather, traffic, sea conditions, tides, etc., that can affect the contractor's choice of equipment and schedule.

Improved communication should result in a lower risk factor for bid prices and a lower incidence of claims due to lack of subsurface information. Quoting from an address by E. H. James (James and Andreae 1978):

There are two solutions to this problem [of the excessive cost of individual site investigations by tendering contractors]. The first involves the willingness of the client and/or his consultant to carry out the necessary investigations at the request of the tenderers, the results being promulgated to all tenderers concerned. A pre-bid meeting attended by the client and/or his consultant, already not uncommon in some countries, is likely the best forum at which the tenderers can make their representations. The second alternative is that interested contractors, if the client is unwilling to carry out further tests, arrange to carry out joint site investigations and share the burden of

the costs, the data obtained being equally distributed amongst the participants. The last method is already sometimes applied.

The owner (the Corps of Engineers) has a right to a timely and correctly executed dredging project. The contractor has a right to a reasonable profit if he does the job correctly. Subsurface conditions exist as they are and cannot be changed. Both the owner and the contractor have risks on the job that they must assume—those over which they have control. Open and continuous interchange of information before the bidding process, and after the contract has been let, will keep both the contractor and the Corps informed of the other's needs and problems.

Improving personnel proficiency for contractors and the Corps of Engineers

A serious effort should be made to maintain a program of continuous education and re-education of both contractor and Corps personnel in dredging fundamentals and in geotechnical methods. This may best be done through the Corps' existing education programs, but with lectures and demonstrations held at District locations rather than a central location.

The fairly continuous movement of personnel within the Corps, especially at junior levels, means that many operating and geotechnical personnel will not develop the depth of knowledge and experience needed for complete understanding of dredging operations. This is also true of contractors, especially in the smaller firms that take advantage of projects specifically set aside for small businesses.

It appears that a policy of evaluating a contractor's equipment and other capabilities *before* he/she is approved for the work should be considered. This should eliminate claims made because of the contractor's assumption that the Corps of Engineers has approved the equipment because it made no effort to inhibit its use on a project.

Development and improvement of acceptable, easily made, readily understood inspection procedures should be continued. Procedures and equipment should be discussed with both the contractor and Corps inspectors at frequent job site meetings. The Dredge Operation Silent Inspector System (DOSIS) should be fully implemented on all dredging contracts.

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